An astrolabe from 14th-century Christian Spain with inscriptions in Latin, Hebrew and Arabic

A unique testimonial to an intercultural encounter

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Contents

1 Introduction

A medieval European astrolabe with inscriptions in both Latin, Hebrew and Arabic which has recently come to light – see Figs. 1-8 – is unique for a variety of reasons.[1] The few Islamic astrolabes that fell into European hands already in the Middle Ages often bear Hebrew or Latin additions to the original Arabic inscriptions. But not a single medieval European astrolabe other than this one bears Arabic inscriptions from before *ca.* 1800. In fact, it bears a set of original Latin inscriptions completed by a set of Arabic ones, and it has an additional layer of markings in Hebrew characters. The last-mentioned appear to predate the others, having been added during the construction and hence prior to the main engraving. In any case, this piece is not the work of a single craftsman, but of at least two and possibly three or even more.

Of all the regions of Christian Europe where astronomy was cultivated during the Middle Ages, Spain has the least number of surviving instruments. This is rather ironical not least because it was in the Iberian Peninsula that Europeans first came into contact with astronomy in general and the astrolabe in particular.[2] Only five medieval European astrolabes can be securely associated with the Iberian Peninsula, this one

[1] The astrolabe has changed hands several times in the last few years and now belongs to an unidentified private collector. A detailed description by this author, condensed from the present study, is in *Christie's 15.4.1999 Catalogue*, pp. 98-107, lot 52 (the illustration of the Hebrew markings on p. 102 was printed back to front). A less detailed description by this author is in *Sotheby's 18.10.2001 Catalogue*, pp. 110-113, lot 111. The piece had become available for study after it was auctioned in 1998 at the Hôtel des Ventes Anticthermal in Nancy. It had been acquired by the vendor as part of a large estate, he being a distant relative of the deceased, who has not been identified. A preliminary description of the instrument prepared for the auction in Nancy by Anthony J. Turner with assistance from Emilie Savage-Smith is listed as *Nancy 28.06.1998 Pamphlet*. This overlooks some of the most historically-important features and contains numerous misinterpretations, especially about the provenance (see nn. 48, 51, 189 and 291).

[2] The most original research on the complicated story of the mathematical sciences in Muslim and Christian Spain is collected in Millás Vallicrosa, *Estudios*, I-II; Vernet, *Estudios*, I-II; and *idem*, ed., *Estudios*, I-II; Samsó, *Ciencias en al-Andalus*, *idem*, *Studies*; and Vernet & Samsó, "Science in Andalusia", as well as various other works by the same authors and other members of the Barcelona school, including *Santa Cruz 1985 Exhibition Catalogue* and *Madrid 1992 Exhibition Catalogue*. Alas none of these works contains any materials relevant to the astrolabe under discussion.
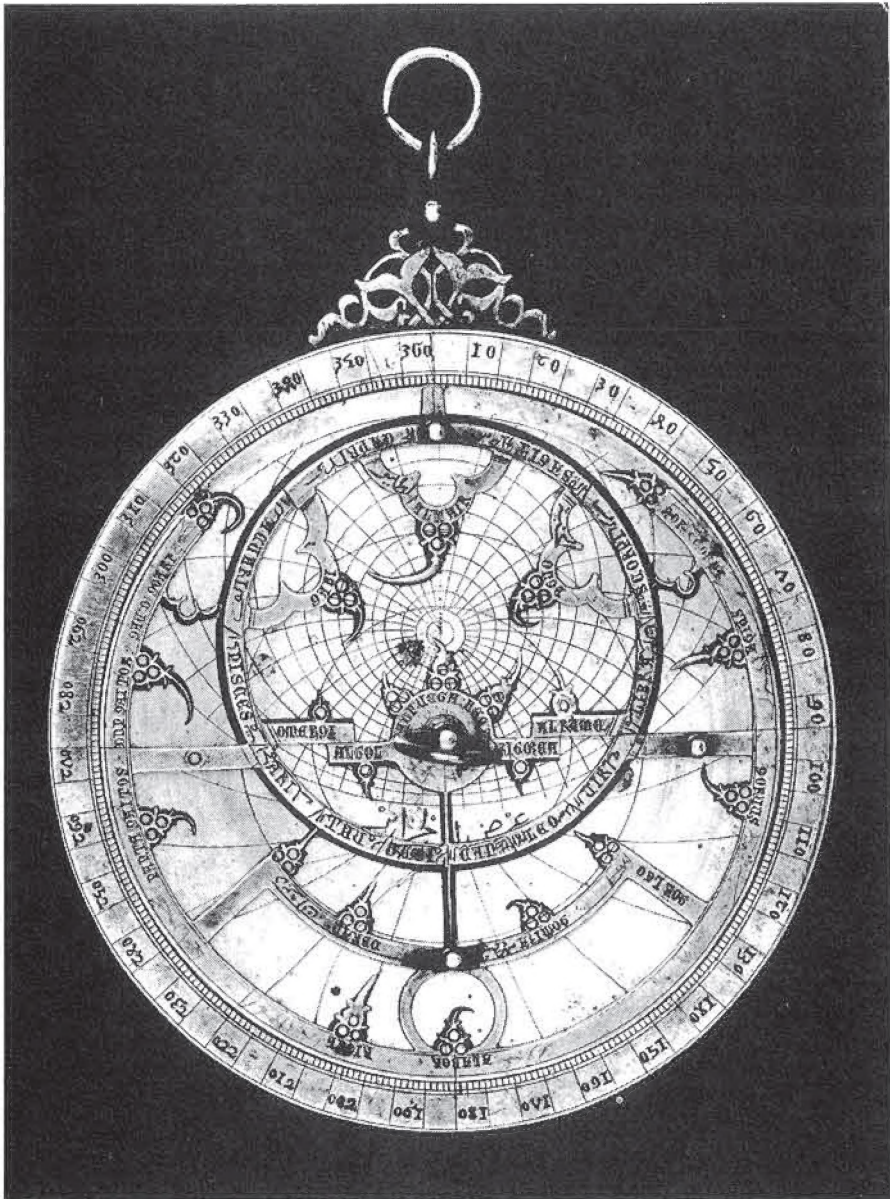
Fig. 1 The front of the 14th-century Spanish astrolabe (#4560).

[The photos in Figs. 1-7 are courtesy of Christie's of London]

and four others from Catalonia – details are given below.[3] Each is quite different from the other in design, and each one underlines how little we know and, without the appearance of new sources such as the astrolabe under discussion, can ever hope to know about medieval astrolabes from the Iberian Peninsula, which are the key to understanding the introduction
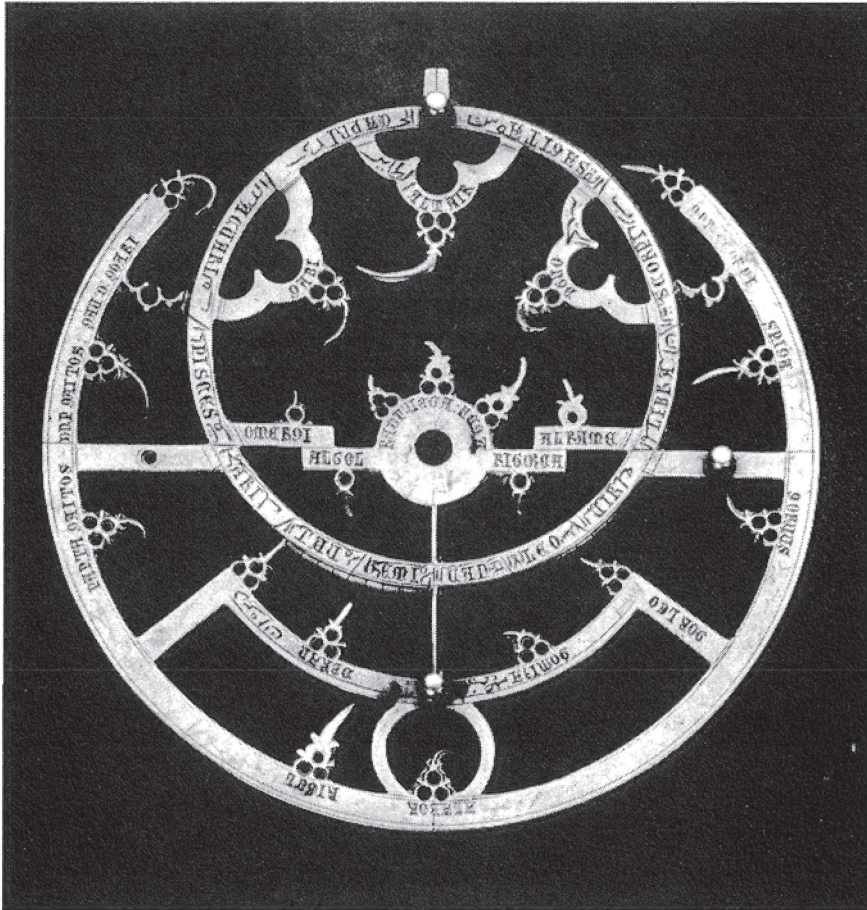
Fig. 2 The rete [Christie's]

[3] See already Gunther, *Astrolabes*, II, p. 305, on the dearth of astronomical instruments surviving from this milieu. Even the *Santa Cruz 1985 Exhibition Catalogue*, entitled *Instrumentos astronómicos en la España medieval*, did not feature a single medieval European instrument from Spain. See also n. 293 below.
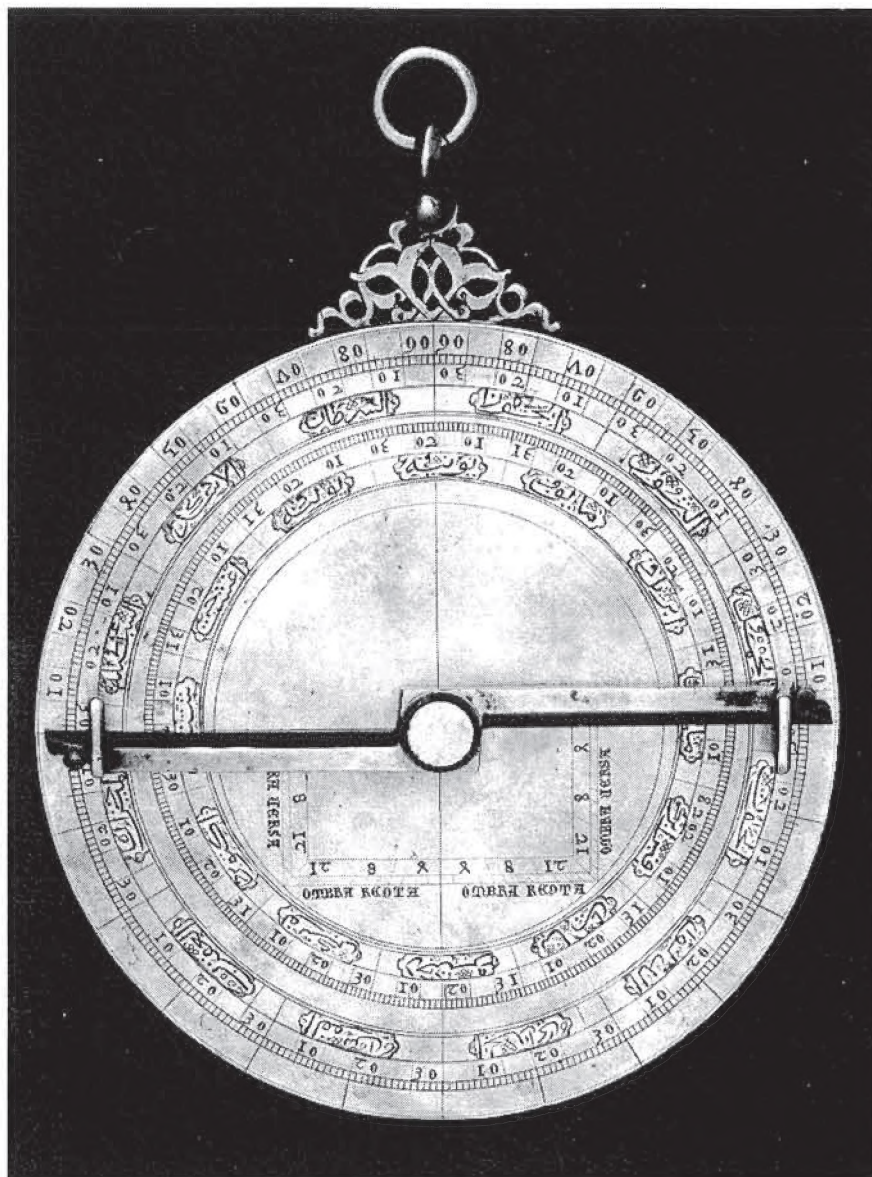
Fig. 3 The back of the astrolabe showing the solar and calendrical scales with the silver cartouches. [Christie's]
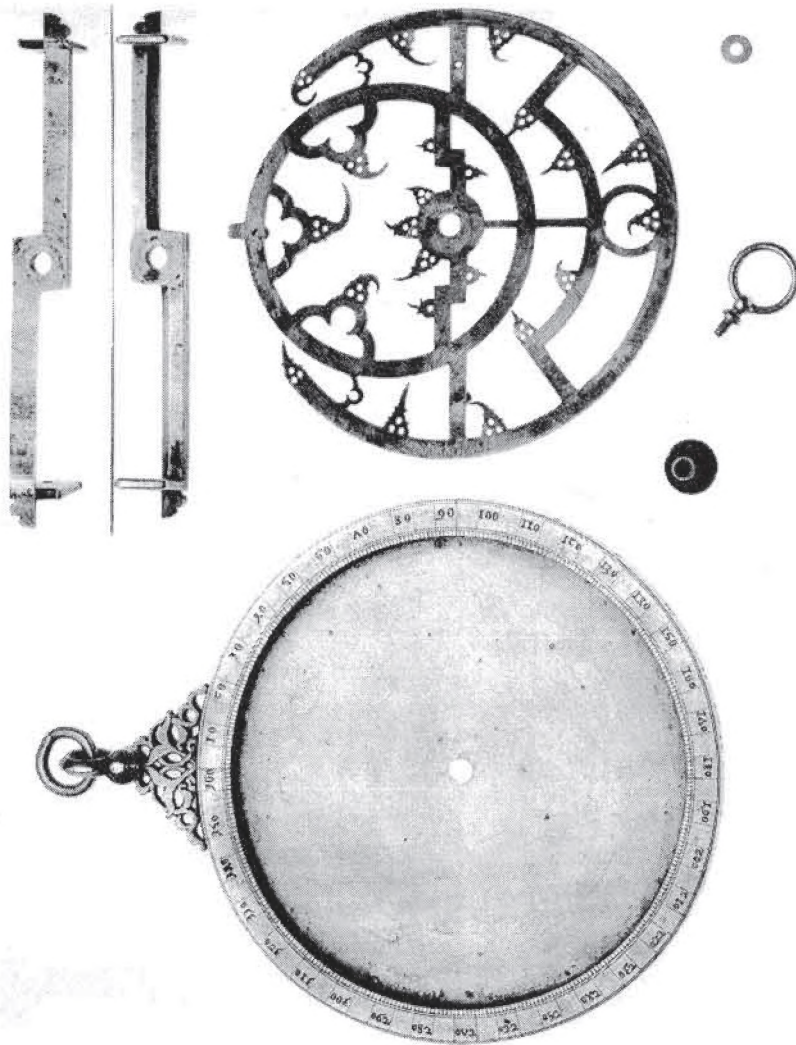
Fig. 4 The mater, back of the rete and the alidade. Notice the impressions of the silver cartouches of the back of the mater. [Christie's]
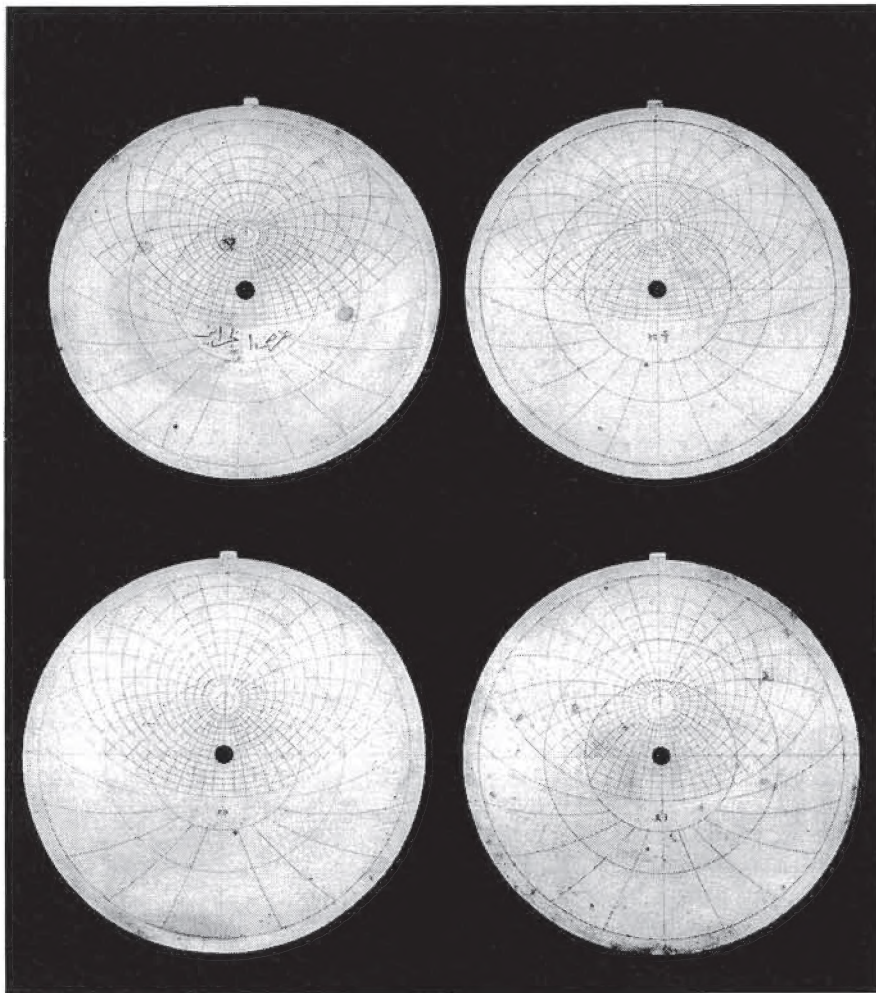
Fig. 5a The plates for the latitude of Algiers (see also Fig. 6a), 32½°, 43° and 40°. [Christie's]

of the astrolabe to Europe. Yet we do know, from manuscript sources as well from one surviving 10th-century astrolabe, that Europeans in Spain started making astrolabes with inscriptions in Latin already in that century. Presumably dozens were actually made there during the Christian Middle Ages. Many more Islamic instruments survive from al-Andalus, that is, that part of Spain which at any given time was in Muslim hands, including some 20-odd from the 11th century (not all complete) and over
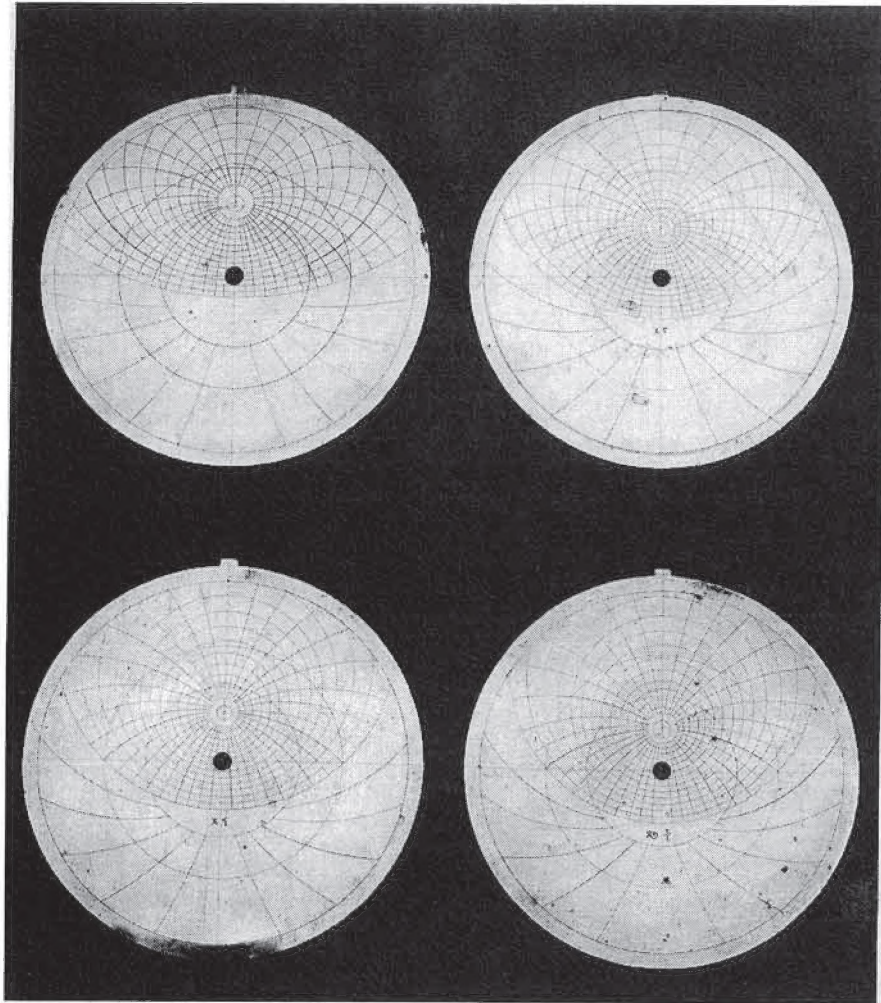
Fig. 5b The plates for [Mecca], 42°, 49½° (see also Fig. 6b), and 45°32. [Christie's]

50 from the 13th-15th centuries (none from the 12th century). Astronomical instruments with inscriptions in Hebrew are rare indeed, in spite of the highly significant role of the Jews in the transmission of scientific

knowledge to the West.[4] Only one medieval astrolabe from al-Andalus or the Maghrib with inscriptions in Hebrew characters survives – see below for details.
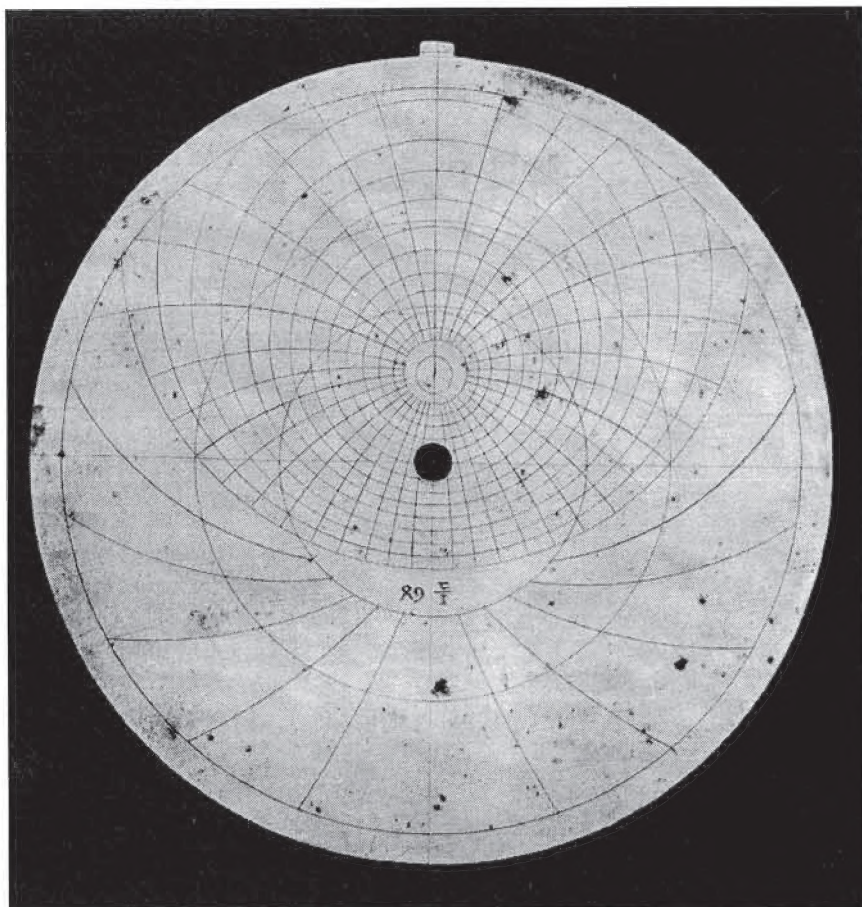
Fig. 6a The plate for latitude 49½°. [Christie's]

[4] A recent survey of Jewish astronomical activity in Spain is Goldstein, "Astronomy of Spanish Jews". Some of the most reliable research on Jewish contributions, rather than their role as transmitters, is collected in Langermann, *Studies*. On instrument texts in Hebrew, albeit from Sicily, see Goldstein, "Hebrew Instrument Descriptions". Glick, "Jewish Contribution to Science in Medieval Spain", is particularly weak on instruments – see n. 293 below.
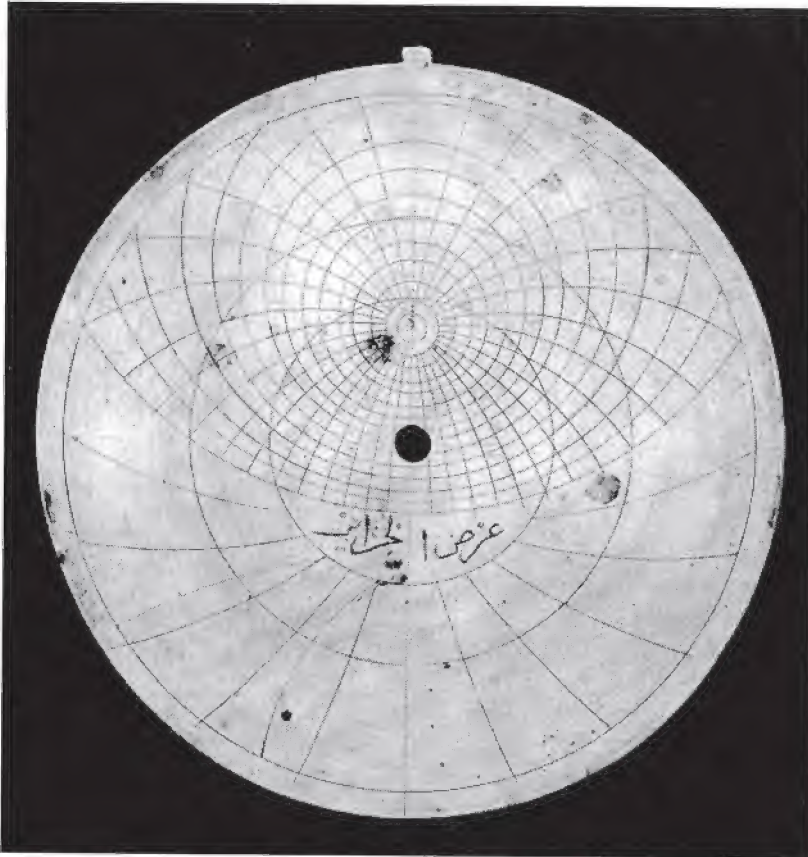
Fig. 6b The additional plate for Algiers. [Christie's]

Fig. 7 The inscriptions by Mas'ūd on the front and back of the boss of the shackle. [Christie's]
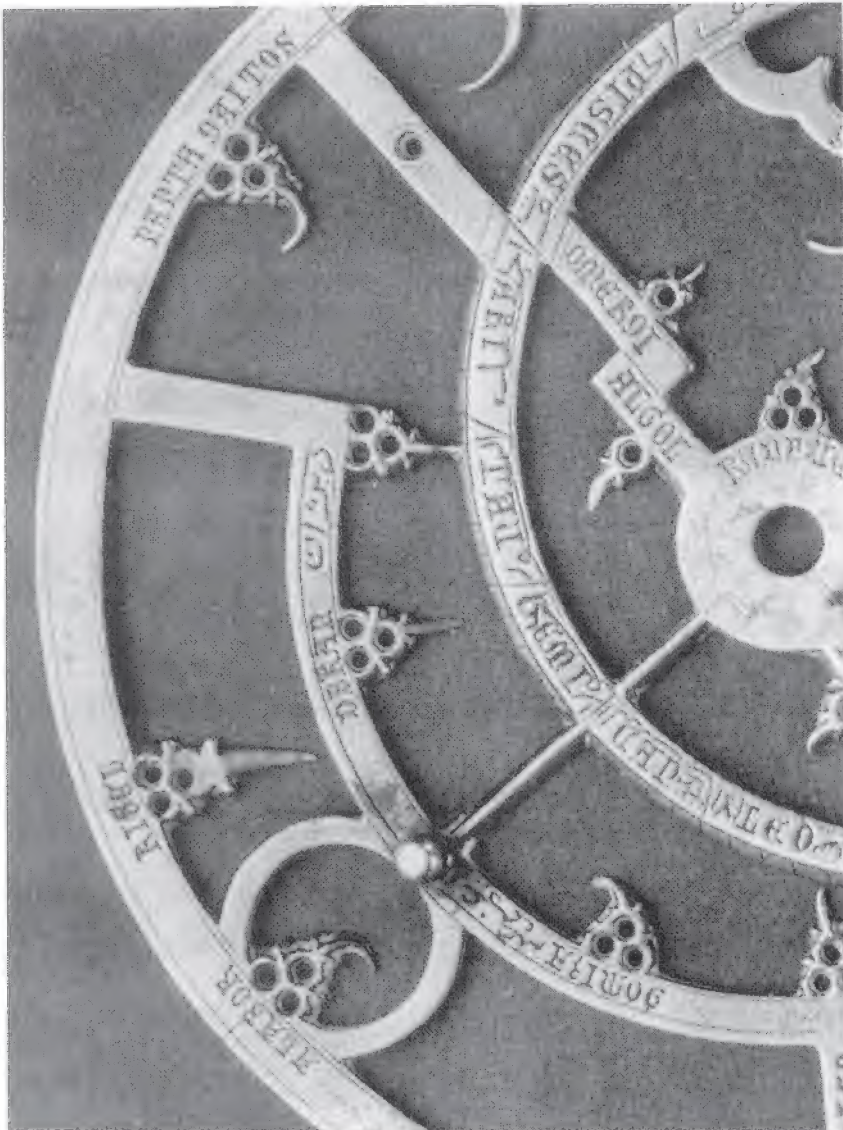
Fig. 8 Details of the astrolabe.

a) Part of the rete, with the star-pointer for Aldebaran near the middle, the name being engraved in abbreviated Latin and Spanish Arabic. Note the additional Arabic names for the zodiacal signs, and the crudely-scratched Arabic names for some of the stars.
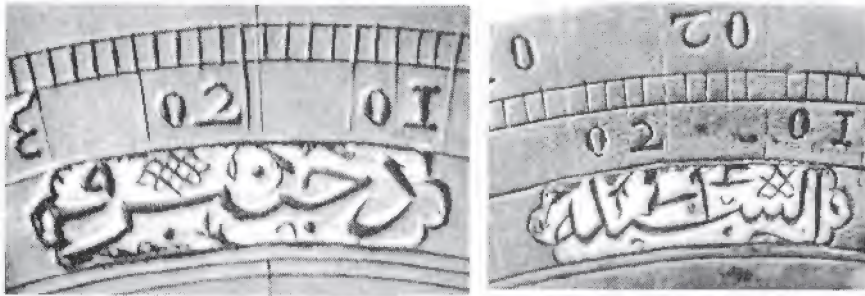
Fig. 8b On the left, the cartouche for December, with the month-name correctly engraved, along with the *feria* '6' and a complete endless knot. On the right, the cartouche for Virgo, showing the name *al-sunbula* incorrectly engraved (without the '*n*'), a *hamza* (?), an *a*-vowel and an *i*-vowel, and a partial endless knot with additional floral strands.
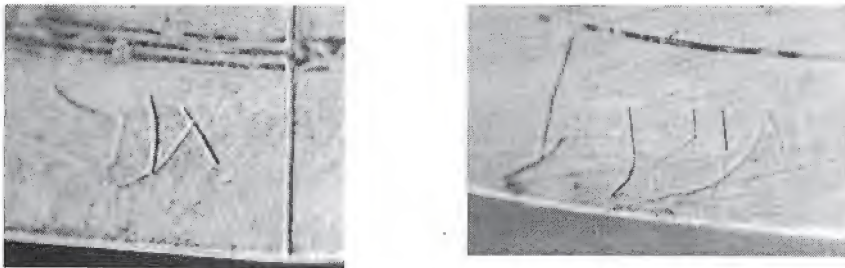
Fig. 8c The latitudes 42° and 49;30° scratched in Hebrew alphanumerical notation on two of the plates
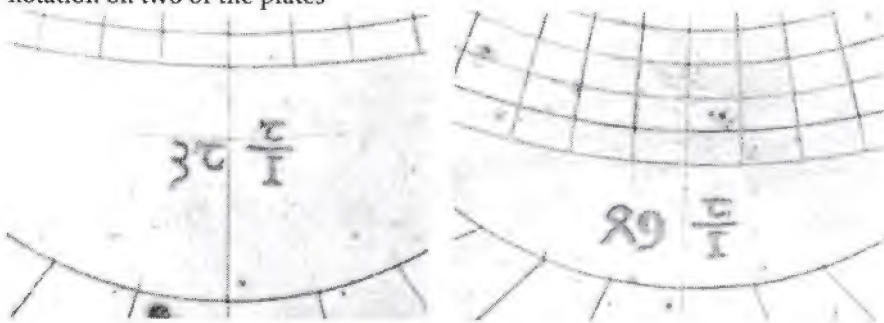
Fig. 8d The The latitudes 32½° and 49½° (for Jerusalem and Reims) represented with the standard medieval forms of the Arabic numerals but for the '2', which is inverted, and the bar fraction for one-half, which is also inverted. [Photos by the author, courtesy of a former owner.]

The engraving on the ecliptic scale

A B C E G I L M N

O P Q R S S T V

The engraving (star-names, shadow squares on back)

A B C D D E F G I L M

N O P R S T V Z Q

The numerals on the scales on the front and back and on the plates

1 2 3 4 5 6 7 8 9 0

The two latitudes featuring fractions

$32\frac{2}{1}$ $49\frac{2}{1}$

The numerals on the outer rim

1 2 3 4 5 6 7 8 9 0

Fig. 9 The forms of the Latin letters and Hindu-Arabic numerals on the astrolabe. [Graphics by Reinhard Glasemann, Frankfurt.]

The instrument, in spite of the Arabic inscriptions, qualifies as a European astrolabe rather than an Islamic one. There is ample evidence that it was made in Central or Northern Spain (Toledo or Saragossa?) in the 14th century, and that it hails from a milieu in which Christians collaborated fruitfully with Muslims and Jews. This *convivencia* was not always voluntary and not always amicable.[5]

Both Toledo and Saragossa had, however, been the scenes of serious scientific activity for several centuries.[6] Toledo had witnessed the ingenious Muslim astronomer Ibn al-Zarqālluh (known in the Latin West as Azarquiel) and the compilation of the hodge-podge of astronomical tables known as the *Toledan Tables*, both in the 11th century, then the capture by the Christians in 1085, followed by the vigorous activities at the court of Alfonso X "el Sabio" in the 13th century. Saragossa had witnessed the brilliant mathematical activities of the Muslim King al-Mu'taman ibn Hūd in the 11th century,[7] but fell to the Christians in 1110. In the 14th century Ptolemy's *Almagest*, which represented the culmination of Greek astronomical knowledge, was still being copied in Arabic in that city.[8] Jewish scholars were associated with the astronomical activities at the court of Alfonso X, and with the astronomical, astrological and cartographic interests of Pedro IV (1336-87), ruler of the Crown of Aragon. Also it is well established that Jews were involved in the metal-trade in Spain in the Middle Ages,[9] and no less that Jewish

[5] On this see *New York JM 1992 Exhibition Catalogue*, entitled *Convivencia* ... , especially the introductory remarks by Thomas F. Glick on pp. 1-9.

[6] See Samsó, "Exact Sciences in Al-Andalus", and *Ciencias en al-Andalus*, for recent overviews of this activity.

[7] See Hogendijk, "al-Mu'taman ibn Hūd".

[8] See also Kunitzsch, *Sternkatalog des Almagest*, I, pp. 6-7, *idem*, "Role of al-Andalus", pp. 148-149, and *idem*, "*Almagest* Manuscript", on a Judaeo-Arabic copy of the *Almagest* partly copied in Calatayud in 1380 with the rest completed in the same city in 1475, and an Arabic copy which came into the possession of a Jewish scholar in Saragossa near the end of the 15th century.

[9] Article "Metals and Mining", in *EJ*, especially p. 1442, where it is stated:
"Many Jewish craftsmen and artisans were engaged in the metal industry in Christian Spain. In 1365 three Jewish smithies are mentioned in Toledo, and there were Jewish workshops in Avila, Valladolid, Valdeolivals near Cuenca, and Talavera de la Reina; a Jewish tinsmith, Solomon (Çuleman) b. Abraham Toledano of Avila, is mentioned in a document of 1375; at the close of the 14th century, Jewish smiths were called upon to repair the copper fountain of Burgos. Before 1391 many Jewish smiths, engravers, and goldsmiths lived in Barcelona. From a Saragossa register of 1401 we learn that there

craftsmen were involved in instrument construction in Spain during the Middle Ages.[10]

Whoever started this instrument gave up his task before it was completed. Death or some other personal catastrophe might have forced this. The one cause of death and disaster that took everyone by surprise in the mid 14th century was the Black Death.[11] Somehow, the instrument then came into the hands of a Muslim Arab named Mas'ūd, who finished it. The Muslims living under Christian domination, the *mudéjars*,[12] were constantly being urged by their co-religionists in the Naṣrid Kingdom of Granada (all that was left of "al-Andalus") and the Maghrib to emigrate to the Islamic world. Perhaps Mas'ūd was a prisoner of the Christians in Spain, but he was no doubt a man of some standing, not least because he was skilled in the craft of astrolabe-making and in the basics of applied scientific knowledge, and no less because he became the first owner. There is evidence that Mas'ūd made his contributions to the astrolabe in Spain but he clearly intended to take the instrument to Algiers, for the Arabic inscriptions specifically mention that city. If the piece did go to Algiers, then it returned to Europe, this time to Northern or Eastern France, by the 16th century, as evidenced by yet another layer of inscriptions. If it was not taken to Algiers, then possibly it went directly from Spain to Eastern France at some time between the 14th and 16th century.

This astrolabe is a singularly complicated piece from a historical point of view, replete with details which can help us better understand the whole instrument once we have come to terms with these details, yet it is silent on some of the most important considerations. The scientific, technological, epigraphic, and art-historical aspects are each of prime importance if we are to begin to understand this object.

were many Jewish engravers and artisans in copper and iron. The local engraver's synagogue was used for the meeting of the community administration."

No source is given for this information, and it is not, as one might expect, Wischnitzer, *Jewish Crafts*. See *ibid.*, pp. 92-113, on Jewish crafts and guilds in medieval Spain. In Shatzmiller, "Professions in Muslim Spain", based on a medieval Maghribī source, virtually every working-class profession is mentioned but, alas, not instrument-making (perhaps because these people were professionals).

[10] See Mackay, "Jews in Spain", p. 40, for a brief overview, and also Vielliard, "Horlogers catalans", pp. 166-167.

[11] See Ziegler, *Black Death*, and also the text to n. 265 below.

[12] See the article "Mudéjar" in EI_2.

In the sequel an attempt has been made to separate description from commentary. The astrolabe cannot be understood without reference to several other early astrolabes, details of which are presented in Appendixes A-B.[13] Much of the comparative material used in this study is taken from the catalogue of medieval Islamic and European instruments currently in preparation in Frankfurt.[14] Some 40 Islamic astrolabes are known from al-Andalus from before *ca.* 1350, but these are of surprisingly little help, except for one earlier Andalusī piece that betrays the same distinctive design of the throne:

> #154, preserved in the Adler Planetarium in Chicago, Ill., an Andalusī astrolabe by Muḥammad ibn Yūsuf ibn Ḥātim dated 638 H [= 1240/41] – see Fig. 10.[15]

Several Islamic astrolabes from Syria or Egypt bear silver inlay as does this piece, yet the silver inlay here is not necessarily influenced by the Eastern Islamic tradition but rather by an Andalusī tradition. A few medieval astrolabes have inscriptions in Hebrew (see §3t) or additions in Hebrew, yet we are not dealing here with an astrolabe in the Jewish tradition. Not a single surviving astrolabe can be securely associated with Southern France before 1400, or even before 1500; some half a dozen of the numerous instruments that can safely be associated with Northern France from before *ca.* 1400 are of relevance to our investigation. As already noted, only four other European astrolabes are known from the

[13] See King, "Instrument Catalogue". Instruments are referred to by their numbers in the International Instrument Checklist (see Price *et al.*, *Checklist*), here preceded by the symbol #.

[14] The majority of the instruments cited in this study have been catalogued already. It is hoped to put this material on the Internet in the not-too-distant future. For the time being, most readers must have recourse to Gunther, *Astrolabes*, a monumental work riddled with errors and long out of date, various catalogues, and the table of contents (from 1991) of the Frankfurt catalogue available at: www.uni-frankfurt.de/fb13/ign/instrument-catalogue.html.

[15] See Gunther, *Astrolabes*, I, pp. 300-301 (no. 154). Gunther unfortunately misdated the piece to 1747 (how, it is not clear). See further n. 130.

Fig. 10 The distinctive rete and distinctive throne on an Andalusī astrolabe dated 1240/41 (#154). Note the two quatrefoils on the rete and the arabesque decoration that is so similar to that on the 14th century Spanish astrolabe. [Photo courtesy of the late Roderick Webster, Adler Planetarium, Chicago, Ill.]

Iberian Peninsula before 1500, all from Catalonia.[16] We shall have occasion to refer to them frequently. These are:

[16] Descriptions in Catalan based on a text in English by this author are to appear in the *La ciència en la història dels Països Catalans* published by the Institut d'Estudis Catalans in Barcelona, currently in press.

#3042, from the late 10th century and now preserved at the Institut du Monde Arabe in Paris. This was first described in 1956 by Marcel Destombes, who, to his credit, recognized it for what it was.[17] More recently the piece has been the object of much controversy, not least because our knowledge of early European astrolabes rests on such weak foundations.[18]

#162, from *ca.* 1300 and now in the Society of Antiquaries in London. This elegant piece was first published in 1893, and was featured by R. T. Gunther in his monumental book on astrolabes published in 1932. It has recently been examined in detail.[19]

#416, also from *ca.* 1300 and now in the National Maritime Museum, Greenwich. A full description is shortly to appear in the new catalogue of the Greenwich astrolabes, but some of its features have been discussed in recent papers.[20]

#3053, made in Barcelona by the Aragonese Petrus Raimundus in 1375 and now in the Museum of Fine Arts, Boston, Mass. This remarkable and extremely elegant piece has not yet been published in detail.[21]

We further note three Andalusī astrolabes that have later additions revealing that they came into the hands of Europeans and/or Jews in the Iberian Peninsular already in the Middle Ages:

[17] Destombes, "Astrolabe carolingien".

[18] See the various studies in Stevens *et al.*, eds., *Oldest Latin Astrolabe*. See also n. 43 below.

[19] See Gunther, *Astrolabes*, II, pp. 306-309 (no. 162); and King & Maier, "Catalan Astrolabe", which contains as an appendix the text of the 1893 publication.

[20] See *Greenwich Astrolabe Catalogue* (forthcoming), also n. 16 above. The plates are discussed in King & Maier, "Catalan Astrolabe", pp. 694-695, n. 60, and the Catalan month-names on the back in Maier, "Romanische Monatsnamen", A, pp. 244-247. The V-shaped frame on the rete was popular on medieval English astrolabes; see King, "Earliest European Astrolabe", fig. 14, for an illustration.

[21] The front is illustrated in King, "Earliest European Astrolabe", fig. 16. See also n. 16.

#116, made in Toledo in 1029/30 and now in the Deutsche Staatsbibliothek in Berlin, has additions in Hebrew, probably also executed in Toledo.[22]

#3622, made in Cordova in the year 1054 and now in the Jagiellonian Museum in Cracow, has additions in medieval Catalan.[23]

#1148, made in Seville in 1230 and now in the Museum of Islamic Art in Cairo, has additions in medieval Spanish, as well as in Hebrew.[24]

No astrolabes with inscriptions in Hebrew survive from medieval Spain. However, a single astrolabe with inscriptions in Judaeo-Arabic, that is, Arabic written in Hebrew characters, survives:

#3915, made either in al-Andalus or in the Maghrib *ca.* 1300, and now in the N. D. Khalili Collection in London. The rete design is related to that on #162.[25] There are several problems relating to this piece,[26] for it was made by someone who was more competent in engraving Hebrew script than in understanding Arabic and astrolabes.

Some remarks about recent research on astrolabes are in order here.[27] Altogether some 150 Islamic and some 150 European astrolabes survive

[22] A detailed description is in Woepcke, "Arabisches Astrolabium". See also Gunther, *Astrolabes*, I, pp. 251-252 (no. 116); Mayer, *Islamic Astrolabists*, p. 75 and pl. II; and n. 248 below.

[23] See Maier, "Romanische Monatsnamen", A, pp. 244-247, and, more especially the detailed description in *idem*, "Astrolab aus Córdoba".

[24] See Maier, "Romanische Monatsnamen", A, pp. 247-249.

[25] See King & Maier, "Catalan Astrolabe", p. 681 and fig. 6 on p. 718.

[26] The description in *Christie's Amsterdam 15.12.1988 Catalogue* is repeated in *Khalili Collection Catalogue*, II, pp. 214-217 (no. 124). The problems of the instrument are overlooked: the plates and their inscriptions are confused (in other words, the latitudes underlying the markings on the plates do no correspond to the latitudes engraved on the plates) and the lengthy inscription makes no sense: see King, "Cataloguing Islamic Instruments", col. 253.

[27] The best introductions to the astrolabe in English are *Greenwich NMM Handlist*, and Hartner, "Astrolabe", A-B. For Spanish readers García Franco, *Astrolabios en España*, remains unsurpassed; it well deserves reprinting with new illustrations. The origin of

from before *ca.* 1500. Each is a historical source that can tell us something, some far more than others. Islamic instruments are usually signed,[28] medieval European ones usually not.[29] Islamic instruments can be associated with various regional schools which are relatively easy to define; for early European instruments there is often no obvious clue to the provenance, and sometimes a given rete design may be, say, English or French or Italian. The study of European rete design is still in its infancy. Islamic instruments are usually dated or easily datable, European ones are seldom dated and we have less control over dating them.[30] A select subgroup of instruments has more than a single layer of inscriptions, from which we can sometimes determine the subsequent fate of the instrument.[31]

some of the standard components on medieval astrolabes is discussed in King, "The Neglected Astrolabe".

[28] On Muslim instrument-makers see Mayer, *Islamic Astrolabists*.

[29] Only seven European astrolabes from before *ca.* 1500 are signed. These are: #292, an English astrolabe signed by Blakenei (dated 1342); #304, also English, undated (*ca.* 1400), with a problematic inscription yet to be interpreted; #3053, made in Barcelona by Petrus Raimundus of Aragon (dated 1375); #548, a 14th-century Italian astrolabe, has additional 15th-century markings by Henricus de Hollandia; and #4523, made by Antonius de Pacent in "Lanzano" (dated 1420); #4506, an Italian astrolabe bearing the initials "KP" in Urbino, 1462 (obviously not by an Italian); and #640, dedicated in Rome by Regiomontanus to his patron, Cardinal Bessarion (dated 1462). In the case of the last-mentioned it is not clear whether or not Regiomontanus actually made it, or whether it was made in Rome or Vienna (see King & Turner, "Bessarion's Astrolabe", pp. 197-198). See further the next note and also n. 43.

[30] Dated European astrolabes from before *ca.* 1450 are only four in number (see the previous note). These are: #291, an English astrolabe dated 1326; #292, Blakenei's astrolabe dated 1342; #3053, Petrus Raimundus' astrolabe dated 1375; #4523, the astrolabe by Antonius de Pacent dated 1420. On some dated astrolabes of the Vienna school between 1450 and 1500 see King & Turner, "Bessarion's astrolabe", pp. 188-190. On some problems of dating medieval Italian astrolabes see King, "Medieval Italian Non-Standard Astrolabe", §A1 and §B2.

[31] For some examples of instruments with more than one layer of inscriptions see *Nuremberg GNM 1992-93 Exhibition Catalogue*, II, pp. 578-581 (on #548, a 14th-century Italian astrolabe with additional 15th-century markings by Henricus de Hollandia, probably in Paris); King, *Ciphers of the Monks*, pp. 132 and 141-142 (on #202, from 14th-century Picardy with numbers expressed in monastic ciphers, and with a later dedication dated 1522 from the Humanist milieu of Louvain); and Maier, "Astrolab aus Córdoba" (on #3622, from 11th-century Cordova, with Catalan additions probably from the 13th or 14th century – Maier has 15th century, which is too late). See also *idem*, "Romanische Monatsnamen", B, on European additions to some Islamic astrolabes, including #116 (on which see also nn. 22 above and 148 & 248 below).

Numerous other features can be used to better understand an astrolabe and place it in its historical context: the engraving (the study of which is likewise still in its infancy) and the numeral forms;[32] the design of the throne and the rete;[33] the choice of stars and their names[34] and positions;[35] the latitudes and/or localities mentioned on the plates;[36] the organization of the solar and calendar scales;[37] the existence of additional markings

[32] A useful guide to relevant number notations is Ifrah, *Histoire des chiffres*. More detailed studies of the Arabic, Hebrew and European notations are listed in nn. 51, 54 and 79. See also King, *Ciphers of the Monks*, pp. 281-317. In this study I use the notation for sexagesimal numbers standard in the modern literature on the history of the exact sciences: thus m;n° stands for m°n′.

[33] See King, "Astronomical Instruments between East and West", p. 160, and also *idem*, "Earliest European Astrolabe", for several illustrations of medieval European astrolabes, in the main previously unpublished.

[34] Arabic star-names are clearly defined and on Islamic astrolabes are generally correctly spelled. On the star-names that one might expect on medieval European astrolabes see Kunitzsch, *Arabische Sternnamen*, based mainly on textual sources; on actual astrolabes there are numerous forms of individual star-names that are even more corrupt than those in the texts. In general it is possible to identify the types of star-catalogues may have been used originally for a particular set of star-pointers, although there are many examples of star-names that have been much corrupted by copying from one instrument to another, without recourse to any manuscripts. The hazards of investigating such names are well revealed by the present study. See also King, "Star-Names on Three Medieval Astrolabes", where the star-names on #4560, #202 and #493, respectively from 14th-century Spain, France and Italy, are investigated.

[35] For the first serious attempt to investigate star-positions on astrolabe retes in the light of medieval knowledge about these positions (and with occasional resort to modern knowledge) see Stautz, *Untersuchungen*.

[36] See King, "Geography of Astrolabes", dealing with the geographical data on all Islamic astrolabes to *ca.* 1100 as well as the earliest European astrolabes (including #3042, #416, #162 and #202).

The plates on the earliest Eastern Islamic, Western Islamic and European astrolabes were specifically for the seven climates of Antiquity: see further n. 264 below. On the importance of the climates in medieval instrumentation see King, "Astronomical Instruments between East and West", pp. 152 and 168-169; *idem*, "Geography of Astrolabes", pp. 6-9; *idem*, *Mecca-Centred World-Maps*, pp. 24, 27-28 and 230-234; and *idem*, *Ciphers of the Monks*, pp. 356-357, 360-361 and 411-415.

[37] These scales feature on the vast majority of Western Islamic and European astrolabes, as well as on some from 12th and 13th-century Syria and Egypt. See further n. 209 below. The dangers of dating instruments solely by the data that can be gathered from the correspondence between the solar and calendrical scales are well known: see Michel, *Traité de l'astrolabe*, pp. 135-141; Zinner, *Astronomische Instrumente*, pp. 138-139;

such as a universal horary quadrant, to provide a quick approximate solution to the problem of determining time from solar altitude for any latitude;[38] the nature of the shadow scales;[39] *etc*. This particular astrolabe even provides new information on the medieval alphabet[40] and the early history of the Hindu-Arabic numerals in Europe.[41]

Instruments have been persistently ignored in studies of medieval metalwork, even though, at least in the Islamic world, they provide the largest single corpus of signed and dated historical objects.[42] There has also been an unfortunate tendency in 20th-century scholarship to dismiss as fakes instruments that do not fit into known categories.[43] It is symptomatic of the state of the field that the earliest surviving European astrolabe, #3042, was deemed highly suspicious by scholars who could not understand it; no amount of scholarship can now undo the damage that has been done to this piece. Metal analysis has not yet been applied to medieval instruments, except in a rather haphazard fashion to two such supposedly suspect pieces.[44] Nevertheless, the study of medieval

Poulle, "Peut-on dater les astrolabes?"; G. Turner, "Carolingian Astrolabe", pp. 426-429, and *idem*, "Dating Astrolabes".

[38] See King, *SATMI*, IXa: On the Universal Horary Quadrant for Timekeeping by the Sun.

[39] *Ibid*., IXa, Appendix B: On Shadow Scales.

[40] On the medieval alphabet a, b, ... , z, followed by the symbols & and **9**, especially as used in lists and concordances in medieval Europe, see King, *Ciphers of the Monks*, pp. 43-45. In the numbering of Section 3 of this paper, I have deliberately used one such medieval technique, a – z, &, **9**, followed by "aa" and "bb".

[41] Another piece, #202, from 14th-century Picardy, bears numbers in a notation completely different from the Roman and Hindu-Arabic notations: see King, *Ciphers of the Monks*, pp. 131-151 and 406-419, and also n. 101 below.

[42] A useful introduction is Ward, *Islamic Metalwork*, with almost exclusively Eastern Islamic examples. See also *Granada-New York 1992 Exhibition Catalogue*, pp. 207-223 and 270-295 (some two dozen metal objects from al-Andalus) and 376-383 (four brass astronomical instruments).

[43] On #3042 (cited already in n. 18 above) see Stevens *et al*., eds., *Oldest Latin Astrolabe*. Some have thought that this was from the 10th century, others that it was from the late Middle Ages, and a few saw it as a modern forgery.

See also King & Turner, "Bessarion's Astrolabe", on #640, an instrument dedicated by the leading astronomer of the 15th century to his patron, which was pronounced suspect after it had been auctioned in 1989. See also the next note.

[44] See, for example, Gratuze & Barrandon, "Nouvelles analyses", for the results of such an analysis of #3042. Here we *are* dealing with a 10th-century instrument but this was not

astronomical instruments in general and astrolabes in particular has taken enormous strides in recent years.[45]

2 Description of the astrolabe

a) Introductory remarks

The astrolabe is in brass with inlaid silver cartouches on the back. It has a diameter of 133 mm – see §3g – and is 5 mm thick. It has been assigned the number 4650 in the International Instrument Checklist.[46]

b) The engraving

The engraving is partly in Latin script, partly in Arabic script, and there are scratches in Hebrew. It is clear that the instrument was started by a Jew, partly engraved by a European and then completed by an Arab, and that the Arab took over the engraving from the European. It may be that they collaborated at least in the inlaying of the silver cartouches on the back, for these were part of the original decoration but the inscriptions on them were engraved by the Arab.

proven by metal analysis because no comparison with contemporaneous metalwork – such as reliquaries, caskets, candlesticks and the like – was conducted. In this case the engraving and also the astronomical and geographical data that the instrument can yield are more useful. See also King & Turner, "Bessarion's Astrolabe", pp. 183-186, for the results of a metal analysis of #640. In this case the authenticity of the instrument dedicated by Regiomontanus to the Cardinal Bessarion was confirmed by finding ten others from the same workshop. This alas does not answer the question: "who actually made it?" (see n. 29 above). One thing that would be useful now is a metal analysis of the whole corpus.

[45] See King, "Astronomical Instruments between East and West", already outdated, and *idem*, *Ciphers of the Monks*, pp. 364-419.

The study of Renaissance instruments has also taken enormous strides. See G. Turner, "Giusti's Workshop"; *idem* & Dekker, "Astrolabe by Mercator", and *eidem*, "Three Astrolabes by Mercator", as well as G. Turner, *Elizabethan Instruments*. For the 16th-century school in Louvain and its Spanish connection see also van Cleempoel, *Louvain Instruments*, and the same author's contributions to *Madrid 1997 Exhibition Catalogue*. On a newly-discovered instrument in the latter tradition see Moreno *et al.*, "Spanish Astrolabe", with some problems of interpretation.

[46] See n. 13 above.

The forms of the Latin letters – see Fig. 9 – are standard, with one exception. A letter '9' resembling, but not identical with, a '9' is used for a hard C (to be pronounced K or Q) in some of the inscriptions. Also there is one ligature OR. See further §2h and §3b.

The European engraver used the medieval European forms of the Hindu-Arabic numerals that were used from the 12th century onwards, with one significant exception. Particularly striking is his use of the "upside-down" '2', which belongs to the forms introduced in Spain in the 10th century.[47] Also he used bar fractions with the numerator on the bottom and the denominator on the top. See Figs. 7 and 9d and further §2j and §§3d-e.

The Arabic script is *naskhī*, but this does not mean that the engraver was from, say, Syria or Egypt rather than from al-Andalus or the Maghrib. In the 14th century *naskhī* script was used for inscriptions in the Naṣrid Kingdom of Granada, which was still in Muslim hands – see §3f.

c) The throne

The throne is elegantly worked with pierced arabesque. This is most unusual on a European astrolabe – see §3h.

d) The suspensory apparatus

A circular ring is attached to a shackle fitted at the top of the throne. The shackle has rounded low conical bosses on the front and back. There is an inscription in Arabic on both sides of the boss of the shackle, which identifies the owner – see Fig. 7.[48] It reads:

[47] The form is "upside-down" only in relation to the form '2' that later became standard. It is in fact that form, which we use today, which is upside-down with respect to the earliest form of the '2' in Europe, that being derived from one of the several Arabic forms by rotation and some stretching. See Kunitzsch, "Hindu-Arabic Numerals".

[48] The second part of this inscription was incorrectly read as a chronogram in *Nancy 28.06.1998 Pamphlet.* The sum of the numerical values of the letters in the phrase *al-wāthiq bi-'l-malik al-ma'būd* is indeed 914, and taking this as a Hijra date, one arrives at an equivalent date of 1508/09 A.D. But making a chronogram out of part of an inscription of this kind goes against the rules of the game, on which see Ahmad, "Arabic Chronograms", and Ifrah, *Histoire des chiffres*, I, pp. 600-604. It *would* be acceptable to use a chronogram in a sentence like "Mas'ūd *acquired* it (*imtalakahu* or something similar) /or/ *finished the engraving* (*atamma naqshahu* or the like) … ".

ṣāḥibuhu 'l-faqīr Mas'ūd
al-wāthiq bi-'l-malik al-ma'būd

which translates:

"Owned by the needy Mas'ūd,
who trusts in the King who is to be worshipped (*i.e.*, God)."

The word *ṣāḥibuhu* has been stretched all around the boss on the front. There is an unhappy *sukūn* (zero-vowel) on the initial *ṣ* (= *ṣād*), and the seat of the *b* (= *bā'*) coincides with the top of the *l* (= *lām*) of *al-faqīr* so that the dot is not visible. The *k* (= *kāf*) in *al-malik* has been repeated above the word. There is a criss-cross decoration below the *m-s* of Mas'ūd. These details are significant – see §3f.

e) The mater

The circumferential scale on the mater is divided into 5° intervals subdivided for each 1° and labelled for each 10° from 10° to 360° – see §3d on the forms.

Around the rim there are divisions for each 15°, corresponding to each hour of the day. These are numbered from 2-12 and again 1-11 in a later (16th-century) European hand – see §3d on these forms too.

The inside of the mater bears no engravings whatsoever. However, the imprints of the silver cartouches on the back and the marks of the hammering to make the brass better receive the molten silver are clearly visible – see Fig. 4.

The back (see below) is riveted to the rim of the mater with 14 rivets, whose outlines are all still visible on each side. (On some medieval astrolabes the mater and back are of one piece.[49])

f) The rete

The rete is of elegant and distinctive design – see Figs. 1-2.[50] There are three half-quatrefoils attached to the inside of the ecliptic ring, each supporting a single star-pointer. The horizontal bar is counter-changed at the ecliptic ring and again between the ecliptic ring and the central circular disc.

[49] On #3042 and #162 the back is brazed onto the rim.

[50] R. T. Gunther would have labelled it "Hispano-Mauresque" – see his *Astrolabes*, II, p. 306.

Between the lower equatorial bar and the circumferential frame there is a distinctive small circular frame. A thin bar connects the equatorial frame to the central disc along the vertical diameter. Two small bars in the form of half-quatrefoils join the upper part of the ecliptic ring to the outer frame. There are four silver buttons serving as handles, two on the horizontal frame outside the ecliptic (the one on the left is missing), one at the top of the ecliptic ring and another at the centre of the equatorial frame above the small circle. For more on the design see §§3i-j.

The scale of the ecliptic is divided into unlabelled 6°-intervals within each zodiacal sign. The signs on the ecliptic ring are named as follows, abbreviated for lack of space in the first half of the ecliptic ring:

ARI – TAU – GEMI – CAN – LEO – VIR
LIBRA – SCORPI – **SAGITA** – CAPRI – **ACUARI** – PISCES

On the two forms in bold, see §3c below. The engraving is not identical to that of the star-names (see below). The equivalent Arabic names are correctly but uncomfortably engraved in the barely adequate remaining space. The forms are the same as those on the back (see below).

The back of the rete bears no astronomical markings other than the circle of the winter solstice on the inner side of the circumferential frame and, on the lower right half of the ecliptic frame, part of the circle of the summer solstice.

g) The star-pointers

Altogether there are 21 star-pointers, with the larger ones having three decorative holes in the base and the smaller ones a single hole. See further §§3k-l. Another pointer at the left-hand end of the lower equatorial frame is a dummy, serving not only the exigencies of symmetry but also to strengthen the rete.

h) The Latin names of the stars

The names of the stars are engraved differently from the names of the zodiacal signs, but not necessarily by a different person. Their forms are a mixture of Europeanised Arabic and Latin, as was standard on medieval European astrolabes. A curious symbol '9' is used for a hard 'C' (see below). Only in the name RIGORCA (no. 8) does the standard form of the

'C' appear, and this is used throughout on the ecliptic ring. Also there is one ligature 'OR' (again no. 8). The colon (in nos. 18 and 21) is used as a separator. A list of the star-names follows, with those of especial historical interest in bold.

1	**PANTA** 9AITOS	12	FE9A
2	ALGOL	13	**ON9E**
3	DBRAN	14	9OR S9ORPI
4	RIGEL	15	**UEGA**
5	ALABOR	16	**RADF**
6	**9OMIZA**	17	ALTAIR
7	9OR LEO	18	**9AUD:9OARI**
8	**RIGORCA**	19	**9ABI**
9	9ORUUS	20	**OMER9I**
10	SPI9A	21	**DNP** 9AITOS:
11	ALRAME		

See §§3m-n for comments on the selection of stars and on the names applied to them.

i) The Arabic names of the stars

The Arabic names have been added secondarily to the European names for four stars in the same hand as that on the boss of the shackle:

3 *dabrān* (the standard form is *dabarān*)
6 *g͟humayṣa* (the standard form is *g͟humayṣā'*)
13 *al-ḥayya*
17 *al-ṭāyir* (the standard form is *al-ṭā'ir*)

See Fig. 8a for the first of these and §3o for comments on these names.

Also the Arabic names of most of the other stars (all but no. 19) have been lightly scratched near the pointers in an inelegant hand. The hand is careless and inexact, quite different from that of the main Arabic inscriptions, but the names, in so far as they can be seen, are essentially correct.

j) The three original plates

Each of the four plates bears standard astrolabic markings for altitudes, azimuths and seasonal hours – see Fig. 5a-b. The altitude circles are engraved for each 6° and the azimuth circles for each 10°, the latter extending only to altitude 78°. Three of the plates are marked in Hindu-Arabic numerals for latitudes:

1a	$32^1/_2$
2a	40
1b	42
3a	43
2b	45
3b	$49^1/_2$

The fractions are both written $\frac{2}{1}$ – see §3e below.

The plates for latitudes $32^1/_2$° and 43° each bear a second horizon, both for latitude *ca.* 45°. Both of these additional horizons are lightly engraved and give the impression that the maker started the plates for this latitude and then changed his mind.

The plate for latitude $32^1/_2$° bears fish-bone markings on the altitude circle for 18° between the solstitial circles, which are different from those on the fourth plate – see §2l and §3v.

These three plates are of different thickness. Their weights in grams are:

P1: 44.4, P2: 49.5, and P3: 53.9.

See further §§3r-s for further details on the latitudes used on these plates.

k) The inscriptions in Hebrew characters

Near the pegs on each side of these three plates the latitudes, this time in degrees and minutes – 32 30, 40, 42, 43, 45, 49 30 – are scratched in

Hebrew alphanumerical notation, using a Sephardic cursive variety of script (sometimes called *rashī*)[51] – see Fig. 8c and further §3t.

l) The fourth plate

The fourth plate is inscribed on one side in Arabic: *'arḍ al-Jazāyir* "latitude of Algiers" – see Fig. 6b. The hand is the same a that of the inscription on the boss of the shackle and of the four Arabic star-names on the rete. There is a *sukūn* on the first *r* (*rā'*), a second on the *l* (= *lām*) and yet another on the final *r* (= *rā'*). A latitude of *ca.* 36°, possibly 35;30°, underlies the astrolabic markings.

This plate for Algiers bears unlabelled curves for the times of the midday and afternoon prayers (*ẓuhr* and *'aṣr*). The altitude curve at 18° above the horizon is distinguished by fish-bone markings between the solstitial circles for the prayers at nightfall and daybreak (*'ishā'* and *fajr*). On the other side there are astrolabic markings for an unspecified latitude, which can be determined by inspection to be *ca.* 21;30°, possibly 21;40°, serving Mecca.[52] The altitude circle for 18° bears fish-bone markings, as on the side for Algiers.

This plate may have been prepared in its raw form by the European who made the others. It is slightly thicker than the thickest of the three other plates: it weighs 57.5 grams. Whilst at first sight the astronomical markings resemble those of the other three plates, closer inspection reveals that they were not engraved by the same person. In fact, it seems that the astronomical markings, as well as the Arabic inscription mentioning Algiers, are by Mas'ūd. See §§3u-v for more details.

[51] On Hebrew alphanumerical notation see Ifrah, *Histoire des chiffres*, 1, pp. 520-529, and also Gandz, "Hebrew Numerals" (does not deal with medieval usage), and Goldstein, "Hebrew Astrolabe". On various examples of Sephardic cursive script see Birnbaum, *Hebrew Scripts*, I, pp. 263-267, and II, nos. 246-251. In *Nancy 28.06.1998 Pamphlet* the markings in Hebrew script are overlooked.

[52] Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. 225-226; and King, "Geography of Astrolabes", p. 13.

m) The back

The back – see Fig. 3 – bears two altitude scales in each quadrant above the horizontal diameter. These are divided for each 5°, subdivided for each 1°, and are labelled for each 10° from 10° to 90° on each side. The corresponding scales below the horizon are divided for each 15° but bear no labels: they define the midpoints of the zodiacal signs on the scale that they bound.

n) The double shadow square

Below the horizontal diameter is a double shadow square, with horizontal shadows labelled OMBRA RE9TA and vertical ones OMBRA UERSA. The shadows are to base 12, as was standard in medieval astronomy, and the scales are divided for each four units sub-divided for each unit and labelled for each four units: 4–8–12.

o) The solar and calendrical scales

The solar scale on the back is divided for each 5° of each zodiacal sign, subdivided for each 1° and labelled for each 10°. The excentric calendrical scale is divided for each 5 days, sub-divided for each single day and labelled for each 10, thus: 10–20–n, where n is the number of days in the month (*e.g.*, 31 for January, 28 for February, *etc.*). The equinox on the solar scale corresponds to March $13^1/_3$ on the calendrical scale. The other equinox is at September $16^1/_2$, and the solstices at June $15^3/_4$ and December $14^1/_3$. See further §§3w-x.

p) The silver cartouches

The silver cartouches for the names of the signs of the zodiac and the months on the back were inlaid at the same time as the graduated scales were engraved. Their borders are contiguous with the circles bounding the scales. The extremities of the "rectangular" cartouches are in the form of a half-quatrefoil. See further §§3y-z.

q) The names of the zodiacal signs

The names of the zodiacal signs on the solar scale are in Arabic, engraved on the first set of inlaid silver cartouches. The names are the standard Arabic ones, namely:

al-ḥamal – al-thawr – al-jawzā[’] –
al-saraṭān – al-asad – al-su[*n*]*bula* –
al-mīzān – al-‘aqrab – al-qaws –
al-jady – al-dalw – al-ḥūt

The *hamza* at the end of *al-jawzā’* has been omitted, as has the *n* (= *nūn*) in *al-sunbula*. On these names various Arabic letters or alphanumerical letters or vowel-signs are also engraved. In the following list and hereafter, ∅ denotes a *sukūn* or zero-vowel sign, and *a*, *i*, *u* the vowels, written in the inscriptions as *ā* (= *alif*), *y* (= *yā’*), and *w* (= *wāw*);[53] * denotes a *shadda*, the sign denoting a doubled consonant, and ’ represents the weak guttural *hamza*. The additional symbols are:

al-ḥamal: ∅ ∅ *u*	*al-thawr*: *u a* or ∅ (squashed)
al-jawzā: ∅ (altered)	*al-saraṭān*: no marks
al-asad: ∅ *z* (= *zāy*) *d* (= *dāl*)	*al-sunbula*: *’ a i*
al-mīzān: *ḥ* (*ḥā’*) or *j* (= *jīm*) ∅	*al-‘aqrab*: ∅ ∅
al-qaws: ∅ *a*	*al-jady*: *a*
al-dalw: *a* *	*al-ḥūt*: *’ a*

These, along with various criss-cross patterns and flourishes, have been used as a kind of decoration. Yet their presence and organization is not entirely fortuitous – see §3& and §3aa below.

[53] As noted in Wright, *Arabic Grammar*, I, p. 8, the standard vowel signs are probably originally derived from these corresponding weak consonants.

r) The month-names

The month-names on the calendrical scale are also engraved in Arabic in the second set of inlaid silver cartouches. They are unvowelled, as is usual:

ynāyr – *fbrābr* [*sic* for *fbrāyr*] – *mārs* – *'bryl* – *māyw* – *ywnyh* – *ywlyh* – *'ghsht* – *shtnbr* – *'ktwbr* – *nwnbr* – *djnbr*

Again there is a surplus of *sukūn*s, namely, on the final *r* (= *rā'*) of *fbr'br*, on the *w* (= *wāw*) of *m'yw*, the *w* of *ywlyh*, and the *sh* (= *shīn*) of *'ghsht*. In addition there are *shadda*s on the *s* (= *sīn*) of *m'rs*, the *t* (= *tā'*) of *shtnbr*, the *k* (= *kāf*) of *'ktbr*, and the *w* of *nwnbr*. These are of particular interest – see §39 (located after §3&, which follows §3z!).

Next to these names is engraved a number in Arabic alphanumerical notation:[54]

alif – *dāl* – *dāl* – *zāy* – *bā'* – *hā'* – *zāy* – *tā'* – *wāw* – *tā'* – *dāl* – *wāw*
1 – 4 – 4 – 7 – 2 – 5 – 7 – 3 – 6 – **3** – 4 – 6 .

The associated numbers are for finding the *feria* or day of the week (the third value from last should be 1 not 3). Thus if the year starts on a Sunday (=1), February will start on a Wednesday (= 4), *etc.*

s) The alidade

The alidade – see Fig. 4 – is of the counter-changed variety with a square plate at the centre and clef decoration at each end. The rectangular sights each have a circular hole 2 mm in diameter and a semicircular cut-out in the half of the base which sits free of the radial stems. A small circular ring attached to the head of a screw with washer fits inside a hollow

[54] On Arabic alphanumerical notation see Irani, "Arabic Numeral Forms"; Kunitzsch, "Letters in Geometrical Diagrams", table 1 on p. 14; and also Ifrah, *Histoire des chiffres*, I, pp. 582-591.

cylindrical shaft attached to a ribbed circular disc. This appears to be original – see §3bb.

3 Commentary

a) Five layers of inscriptions

We can distinguish five different layers of inscriptions, of which the main ones, namely, the second and third, appear to be contemporaneous and the first cannot have preceded them by very long (a matter of days at the most). The fifth layer was certainly added a long time thereafter (16th century?).

1 The Hebrew inscriptions scratched on three of the plates, apparently intended only as an *aide-mémoire* to the maker.
2 The "Latin" inscriptions[55] on the rete, back and three plates.
3 The Arabic inscriptions on the boss of the shackle, the rete, the back, and the fourth plate. These were all engraved by the first owner, Mas'ūd.
4 The second set of Arabic inscriptions scratched on the rete.
5 The 16th-century Northern / Eastern French numeral forms engraved around the outer rim.

The possibility that the Latin inscriptions were engraved by the same person who scratched the Hebrew characters on the plates cannot be excluded. Thus we would have four different layers (with 1a and 1b by the same person):

1a The Hebrew construction marks on the plates.

[55] Here and elsewhere the term "Latin" is used advisedly, and in preference to, say, "Gothic". The "Latin" inscriptions include the medieval forms of the Hindu-Arabic numerals on the various scales on the front and back as well as on the plates, the names of the signs on the ecliptic ring, the star-names, and the inscriptions on the shadow-square on the back. Note that the engraving on the ecliptic ring is slightly different and from an orthographical point of view significantly different from that used for the star-names (for example, no '9' is used).

1b The "Latin" inscriptions on the rete, back and three plates.
2 Mas'ūd's Arabic inscriptions on the boss, the rete, the back and the fourth plate.
3 The second set of Arabic inscriptions on the rete.
4 The Northern / Eastern French numeral forms around the outer rim.

Yet another possibility must be mentioned, namely, that the first and fourth of the five sets of inscriptions were made by the same person, after the Latin and the main Arabic inscriptions had been completed and presumably after the instrument had passed out of the hands of Mas'ūd, its first owner. The probability that a Jewish owner would engrave the latitudes in Hebrew alphanumerical notation for his own purposes (rather than for construction purposes) and would have added the second set of Arabic markings should be considered. In favour of this hypothesis, there is the fact that both sets are scratched rather than engraved. A Jew competent in Arabic might have thought that the star-names should all be in Arabic, and the Hebrew alphanumerical notation is basically the same as the Arabic one anyway – only the script is different. There is a substantial corpus of inscriptions and literature in Judaeo-Arabic, that is, Arabic written in Hebrew script from medieval Spain and the Maghrib, as well as from other parts of the Islamic world.[56] In other words we would have four main layers of inscriptions (with 3a and 3b by the same person):

1 The "Latin" inscriptions on the rete, back and three plates.
2 The Arabic inscriptions on the boss, the rete, the back and the fourth plate. These were engraved by the first owner Mas'ūd.
3a The second set of Arabic inscriptions on the rete.
3b The Hebrew inscriptions scratched on the plates.
4 The Northern or Eastern French numeral forms around the outer rim.

[56] See the article "Judaeo-Arabic" in EI_2.

Against this hypothesis is the fact that the second set of Arabic inscriptions was clearly added after Mas'ūd engraved his four star-names, for these are not included in the second set.

b) *The Latin engraving*

The engraving of the "Latin" star-names, the latitudes on the three original plates, and the inscriptions on the back is in a single hand. The engraving of the names of the signs on the ecliptic ring is different, but not necessarily by another person. Both sets of forms of the letters are standard for 13th- and 14th-century Spain.[57] They are shown in Fig. 9.[58]

The special '9' form for hard 'C', which is used with only one exception in the star-names and also in the word RE9TA on the back, but not on the ecliptic ring, is not attested on any other known medieval instrument. A more usual form of 'C' is found in the star-name RIGORCA (no. 8). It seems that '9' is used when the sound is a hard 'C' or a 'K' or a 'Q'. The normal 'C' in RIGORCA may mean that it was pronounced RIGORÇA or RIGORSA.

The letter 'Q' was written like '9' in certain Spanish manuscripts from the 13th to the 15th centuries,[59] as a result of writing the tail of the 'Q' to the left rather than the right. The hypothesis that the '9' here is intended to be a 'Q' is not tenable. For on the astrolabe it is not just 'Q' which is engraved as '9' but also, for example, the hard 'C' as in 9OR and RE9TA. And some of the same Spanish alphabets have a 'K' whereas others do not. So we must look beyond the standard alphabets.

The symbol '9' is actually a letter of the expanded medieval "Gothic" alphabet.[60] This consisted of the letters 'a' to 'z',[61] and in addition the two

[57] The resemblance to the engraving on the Catalan astrolabe #162, datable *ca.* 1300, and #3053, made in Barcelona in 1375 by an Aragonese, is striking. On the former see the letters and numbers reproduced in King & Maier, "Catalan Astrolabe", p. 716, fig. 4, drawn by Reinhard Glasemann, Frankfurt.

[58] These were also drawn by Reinhard Glasemann.

[59] See García Villada, *Paleografía española*, I, pp. 328, 330 and 335, as well as p. 356 *ad* fig. 112 in vol. II, and also López de Toro, *Abreviaturas hispanicas*, tables I-II.

[60] See already n. 40 on this extended alphabet.

letters '&', the "ampersand" that we still use today, and a letter '9' which has no name, but which was "so graceful and chaste in early and middle gothic".[62] This '9' is attested already in Roman Antiquity: it is mentioned by the grammarian Valerius Probus in the 1st century. Originally conceived as one of the symbols of the Tironian Notes, the Roman speed-writing notation devised by Tiro, *amanuensis* of Cicero (*ca.* 63 B.C.),[63] in the Middle Ages it served firstly as an abbreviation for the prefix *con-* or *cum-* and, secondly, albeit upper-case and in smaller versions which sometimes resemble a comma, the ending *-us*. It is well known to all those familiar with Latin and medieval palaeography and its almost perverse systems of abbreviations,[64] and its presence has already been noted on medieval astrolabes.[65] On this astrolabe we find the '9' used as a letter of

[61] With or without certain letters such as 'h', 'j', 'k', 'q', 'v', 'w' and 'y', depending on the language involved.

[62] Quoted from Thomson, *Latin Bookhands*, notes *ad* no. 17.

[63] On the Tironian notes see Kopp, *Lexicon Tironianum*, and Costamagna *et al.*, *Notæ Tironianæ*.

[64] The abbreviation '9' is discussed in Chassant, *Dictionnaire des abréviations*, pp. xxxii and xxxiv, Prou, *Manuel de paléographie latine et française*, pp. 67 and 68, and Cappelli, *Lexicon abbreviaturarum*, pp. XXV-XXVI, where the two different forms are distinguished; Delisle & Traube, "Signe abréviatif"; Poupardin, "Abréviation"; Schiaparelli, "Note paleografiche", pp. 248-249; Laurent, *De abbreviationibus*, pp. 43-44; and Bischoff, *Palaeography*, pp. 151-168.

For lists of words in Latin and French beginning with this abbreviation see Chassant, *Dictionnaire des abréviations*, pp. 109-112 and 150; and Prou, *Manuel de paléographie latine et française*, pp. 343-349 and 378. Cappelli, *op cit.*, pp. 68-85, gives numerous examples but not of '9' being used strictly as a letter of the alphabet. Various examples of the standard uses of the '9' from medieval Spanish manuscripts are illustrated in Millares Carlo, *Paleografía española*, II, pp. 112-113, pl. 76B, nos. 73-81 (for *con-*) and 85-96 (for *-us*).

On practice alphabets found in medieval sources see Wolpe, "Florilegium Alphabeticum"; the article "Abécédaire" by H. Leclercq in *Dict. arch. chrét.*, I, cols. 45-61; and Ullman, "Abecedaria".

[65] An additional 15th-century inscription on a 14th-century Italian astrolabe, #548, reads: *Henric*9 *de Hollandia* 9*posuit me*, where the verb is *composuit*, meaning here "put together in its present form". There is also a plate for *pari*9, that is, Parisius. See *Nuremberg GNM 1992-93 Exhibition Catalogue*, II, p. 580 (*ad* no. 1.74) and figs. 1.74.3-4.

the alphabet, which is an extremely rare palaeographic phenomenon, but which must be associated with a particular location and epoch. The question is: can we use this unusual feature to identify the provenance?[66] Until the present time it has *not* been possible.[67] Apparently the '9' was used in 12th-century Aragon for a simple 'S',[68] but the use of '9' for a hard 'C' on a 14th-century astrolabe seems to constitute the first (and

Likewise, the star-name 9*iuncte* for *coniuncte* is found on an Italian astrolabe #4509 from *ca.* 1300 – see *Amsterdam 1990 Exhibition Catalogue*, p. 101 (no. 186) and p. 106. The 8th month-name is engraved as *AUG9TUS* (*AUG9T9* would be more consistent!) on a 13th(?)-century astrolabe of uncertain provenance, #558 – see *Nuremberg GNM 1992-93 Exhibition Catalogue*, II, p. 576 (*ad* no. 1.72).

[66] See the study Sed-Rajna, "Toledo or Burgos?", dealing with illuminations in a corpus of medieval manuscripts.

[67] The following works have been consulted in addition to various catalogues of manuscript collections in Madrid, Toledo and Salamanca:

Madrid MAN Catalogue, on epigraphic inscriptions; Thomson, *Latin Bookhands*, with numerous dated extracts of manuscripts arranged according to provenance; García Villada, *Paleografía española*; Millares Carlo, *Paleografía española*; Gimeno Blay, "Escrituras bajomedievales", alas restricted to collections in Valencia; Cooper, "Language of Late Medieval Aragon", a linguistic review of a corpus of late medieval documents from Upper Aragon; Mateu Ibars, *Braquigrafía de sumas*, on abbreviations in numerous Spanish Latin numerous scholastic texts from the 13th to the 16th century; Mateu Ibars & Mateù Ibars, *Colectanea paleográfica*, dealing with Aragonese manuscripts and richly documented with sample alphabets; Marín Martínez & Ruiz Asencio, *Paleografía y diplomatica*, with numerous regional examples of alphabets; Arnall i Juan & Pons i Guri, *L'Escriptura a les terres gironines*, dealing with examples from Girona; and Usón Sese, *Escritura en Aragón*, dealing with calligraphy in Aragonese texts from the 11th to the 16th century.

From the extracts presented in Thomson, *Latin Bookhands*, it appears that French copyists had more of a predilection for the use of '9' for *con-*, *etc.*, than their counterparts elsewhere in medieval Europe, but this may be an illusion.

[68] This is stated categorically in Millares Carlo, *Paleografía española*, I, p. 113 ("si lo usó a veces con valor de simple *s*, y así se lo ve en documentos aragoneses del siglo XII"), but the reference is alas a blind one, since the sources referred to in the associated footnote, namely, Delisle & Traube, "Signe abréviatif", and Poupardin, "Abréviation", deal only with the symbol '9' in French and Belgian manuscripts.

We also note the use of 'Cc' for 'ç' in a Spanish manuscript dated 1422 – see García Villada, *Paleografía española*, p. 352 *ad* facsimile no. 109. There is no distinction made between *c* and *ç* in the organization of an Aragonese glossary from 14th-century Toledo – see Castro, *Glosarios latino-españoles*, pp. 3-5.

perhaps only?) evidence of this particular phenomenon, thus being, at least in my opinion, of extreme epigraphic importance,[69] and one that we can only ever hope to understand *within the context of medieval Spanish epigraphy*.

In addition, a ligature OR is used in the same star-name RIGORCA. This particular ligature is common in early (9th- to 12th-century) manuscripts.[70] It is probably not insignificant that a ligature AL is used on the medieval Catalan additions to an 11th-century Islamic astrolabe from Cordova (#3622),[71] as well as on various later medieval astrolabes.

Only once in the recent past has an epigrapher turned his attention to the engraving on a medieval astrolabe, confirming from the distinctive forms used for the lettering what is evident from other aspects of the same instrument.[72] The spadework of epigraphers may eventually lead to a localisation of the distinctive Latin engraving of the astrolabe under discussion.

[69] I thus beg to differ with two colleagues. Firstly, Paul Kunitzsch of Munich (letter of 6.09.2000) wrote: "I am not sure whether ... the 9 was really intentional for a "hard C", or just simply a graphical variant, a personal [quirk] of the craftsman." Also Martin Hellmann of Heidelberg, who has recently published a doctoral thesis on a medieval commentary to Boethius partly written in Tironian Notes, and has also reviewed my recent findings on a missing connection between Ancient and medieval shorthands (see his "Review of King, *Ciphers of the Monks*"), points out (private communication on 30.11.2002) that: (1) there was no need in Latin for another symbol for a hard 'C', since 'C', 'K' and 'Q' were available; (2) it would not be abnormal for a scribe to make a 'Q', written '9', out of a 'C' to represent a hard 'C'; further (3) a graphic double-form of 'CC' (see previous note) is for him nothing special.

[70] W. Mayer, "Buchstaben-Verbindungen", pp. 36-38. See also article "Paleography" in *DMA*, especially IX, p. 346a.

[71] See Maier, "Astrolab aus Córdoba", pp. 121 and 127. Here the ligature is used in star-names beginning with the Arabic article *al-*, and this feature is all the more remarkable because the star-names are *punched*.

[72] See Mundó, "Analyse paléographique de l'astrolabe 'carolingien'". The basic documentation of letter-forms on medieval instruments is also important: see Glasemann, "Zwei mittelalterliche französiche Astrolabien", p. 226. The engraving on Renaissance instruments is under better control, thanks mainly to the labours of Koenraad van Cleempoel and Gerard L'E. Turner.

c) *Traces of vernacular influence in the Latin inscriptions*

Traces of vernacular influence on medieval Latin, let alone vernacular Romance dialectal forms, can be extremely useful indicators of the provenance of instruments. Recently, such evidence has been exploited for the first time.[73]

The form ACUARI for AQUARI(US) may be nothing other than an orthographical variant (C for Q) rather than a dialectal one. In the erroneous star-name CAUD:COARI (no. 18 in the star-list) it seems that we are dealing with a more developed vernacular form (A)COARI. An early-13th-century Andalusī astrolabe from Seville with later Northern Spanish inscriptions (#1148) has AQARI, which our engraver would probably have rendered as A9ARI. Both the astrolabe of Petrus Raimundus of Aragon (#3053), made in Barcelona in 1375, and the medieval Catalan additions to an 11th-century astrolabe from Cordova (#3622) have ACARI. The switch *qu* → *c* in Spanish Latin is attested.[74] On the 14th-century Picard astrolabe (#202) we find ACARIUS.[75] SAGITTARIUS was spelled with one 'T' as often in the Middle Ages as it is today.[76]

The form OMBRA for Latin UMBRA reveals Spanish or French vernacular influence. It should be borne in mind that OMBRA is still Latin, albeit with vernacular influence, rather than a true Romance form (such as *sombra* or *ombre*).[77] The same phenomenon of short *u* → *o* is

[73] See Maier, "Romanische Monatsnamen", A-B. In King & Maier, "Catalan Astrolabe", pp. 686-690, it was the Catalan forms of star-names and month-names that were used to establish the provenance.

[74] Castro, *Glosarios latino-españoles*, p. xliv.

[75] These variants are listed in King, *Ciphers of the Monks*, p. 411, n. 12. See also Maier, "Astrolab aus Córdoba", p. 126.

[76] See King, *Ciphers of the Monks*, pp. 410-411.

[77] On the switch *u* → *o* see Castro, *Glosarios latino-españoles*, p. xxxiv. On the fate of UMBRA in Spanish see Corominas, *Diccionario*, V, pp. 298-300, especially p. 298b. See also the Renaissance Italian astrolabe with OMBRA in Gunther, *Astrolabes*, II, p. 331.

attested in the star-names ON9E (no. 13), OMER9I (no. 20) and (RIG)ORCA (no. 8 – see below).

Also in the star-name RIGORCA (no. 8) it seems likely that the ORCA, pronounced ORSA, is from Latin URSA(E). No other explanation comes to mind. Here again the change could be taken to display Spanish or French influence, or even Italian: compare Spanish *osa*, French *ourse*, and Italian *orsa*. In the case of RADF (no. 16) instead of RIDF or REDF it may be that we are witness to a change $i \rightarrow a$ that is also attested in medieval Spanish Latin.[78]

d) Numerical considerations

The numeral forms on the scales of the mater and back, as well as the latitudes on the three original plates, are, with one exception, the standard medieval forms of the Hindu-Arabic numerals.[79] They are shown in Fig. 9.

The '2' is always written – as we would say – upside-down. This form of the '2', although not attested on any known astronomical instrument, is found throughout the Middle Ages and as late as the 16th century, although it was generally replaced by the more common upright form, which we use today.[80] One theory proposed to explain why some of these numerals have a different aspect from the Hindu-Arabic numerals that were introduced in Spain is that the numbers on the abacus stones were seen in different aspects depending on where one stood in relation to the device.[81] On the other hand, the inverted form of the '2' is standard in the

[78] See Castro, *Glosarios latino-españoles*, p. xxxvi, especially the form *aladada* via perhaps *alhidada* or *alidada* from Arabic *al-'iḍāda*, meaning "alidade". This form is not listed in Kunitzsch, "Fachausdrücke", pp. 527-528 (pp. 73-74 of the separatum).

[79] The most useful single source is Hill, *Arabic Numerals*, based mainly on manuscripts in the British Library. See also Ifrah, *Histoire des chiffres*, II, pp. 341-373, and King, *Ciphers of the Monks*, pp. 309-317.

[80] Hill, *Arabic Numerals*, pp. 28 and 44. See also Juschkewitsch, *Mathematik im Mittelalter*, p. 355, fig. 98, for some 19 different forms of the '2' from medieval manuscripts (other forms could be added), and Ifrah, *Histoire des chiffres*, I, p. 880 on the development of '2'.

[81] Beaujouan, "Rotation des chiffres".

earliest European forms of the Hindu-Arabic numerals, used from the 9th century to the early 13th, but the forms of the other numerals on this astrolabe are not found in European sources in Spain before the 12th century.[82] Furthermore, no other medieval source, object or manuscript, having this combination of the "old-fashioned" '2' and the "new" "Gothic" forms of the other numerals comes to mind.[83] In the light of our engraver's use of the Tironian abbreviation '9' as a letter of the alphabet (see §3b), we should at least mention that in 13th-century Toledo the Tironian abbreviation for Latin *et* also looked like an inverted '2'.[84] Could this perhaps be the reason why our engraver preferred this inverted form?

The history of the Hindu-Arabic numerals in Europe has yet to be written:[85] suffice it to say that first, there existed various forms of the nine symbols and zero-symbol in use in each of the Islamic and Byzantine worlds, as well as in each of Spain and Italy, and second, the upside down variety of the '2' was already old-fashioned by the 14th century. It should be borne in mind that the numerals were engraved on this instrument less than two centuries after they had been introduced in Spain, and that in the vast majority of Spanish manuscripts (not necessarily scientific ones)

[82] The two tables of forms in Ifrah, *Histoire des chiffres*, II, pp. 348 and 362, display respectively 23 examples of inverted '2's from between 976 and the beginning of the 13th century, and 22 examples of upright '2's from the period between the 12th century and the early 16th. See, most recently, Burnett, "Abacus at Echternach", pp. 94-95, 102-103 and 106-107, on this inverted '2' in Echternach (Luxembourg) *ca.* 1000.

[83] In a little-known article Piccard, "Les chiffres chez les anciens et les modernes", published in Lausanne in 1860, in the table after p. 194, we do find two sets of digits 1-9 with standard medieval forms of all numerals including '4', '5' and '7', but with inverted '2', of which Piccard claims that these are from Sacrobosco and Roger Bacon. Alas he gives no further information on the sources.

[84] See Thomson, *Latin Bookhands*, *ad* no. 117, a manuscript copied in Toledo in 1253/54, featuring this abbreviation with a long horizontal stroke.

[85] Studies such as Lemay, "Arabic Numerals", and Beaujouan, "Rotation des chiffres", like all other modern studies, suffer from the fact that the authors are familiar only with the Latin tradition. Before looking at the forms attested in early medieval Europe it is instructive to note the divergent forms existing in the Islamic world before some of them were transmitted to Europe. For new light on this topic see Kunitzsch, "Hindu-Arabic Numerals"; and King, *Ciphers of the Monks*, pp. 309-317.

from the 13th to 15th century Roman numerals rather that Hindu-Arabic numerals are used for dating.

The numeral forms on the outer rim of the mater are shown in Fig. 9. These are distinctly 16th-century Northern French or German in form, notably the 'Z'-shaped '2'.[86] This form of the '2' could be Spanish, and is attested there already in the 14th century,[87] but it is the whole set which suggests a later and also a more northerly provenance.[88] Actually, it is the forms of the '4', '5', '7' and '8' that necessitate this late a dating. In fact, the ensemble resembles the forms used in the illustrations of the rete and back of an astrolabe (#203) in the treatise *L'usaige de l'astrolabe* by Dominique Jacquinot, printed in Paris in 1545.[89] One may wonder whether these numerals were added in Lorraine, where the astrolabe was to be found, since when we do not know, and until 1998.

e) The bar fractions

The two bar fractions on the plates for latitudes $32^1/_2°$ and $49^1/_2°$ are the earliest original attestations of bar fractions in Europe on an astronomical instrument.[90] In fact they are the only undisputed occurences on an

[86] This form of the '2' is found already in 12th-century French manuscripts (see Ifrah, *Histoire des chiffres*, II, p. 362), on the French astrolabe #428 from *ca.* 1300, and on the astrolabes of the workshop of Jean Fusoris of Paris *ca.* 1400 (see the article in *DSB* and the illustration of #192 in Gunther and in Poulle, *Instruments du Moyen Age*, pp. 20 and 22).

[87] The 'Z' form for '2' is found alongside a rounded '2' on #3053, the astrolabe made in Barcelona in 1375 by an Aragonese: here, however, the 'Z' is, as often as not, written backwards!

[88] It is, of course, possible that these numbers were added in Spain in the 16th century. Thus, for example, the numerals engraved on #165, an astrolabe made in Saragossa in 1558, have a rounded form of the '2' and other standard Renaissance forms. Also the forms of 18 sets of Hindu-Arabic numerals from between the late 15th and the 16th century from Spanish documents presented in Labarta & Barceló, *Números y cifras*, pp. 37 and 45, do not correspond to the numerals added to our astrolabe.

[89] Illustrated in Gunther, *Astrolabes*, II, pp. 350-352 (no. 203).

[90] On the plates of #621, a composite 14th-century Italian (?) astrolabe, one of the latitudes, presumably that corresponding to the location of the maker, is engraved as 43 ÷,

instrument before the late 16th century,[91] when we find $^1/_4$ appearing at the end of December (as $31^1/_4$) on calendar-scales of astrolabes from Louvain (workshop of the Arsenius brothers, *etc.*).[92] In some 16th-century additions to an 11th-century Andalusī astrolabe #117, additions doubtless made in Spain, the fraction in the latitude $41\frac{1}{2}°$ on one of the plates is written without the bar altogether.[93] Now on the astrolabe under discussion, the fractions are written – as we would say – upside down, thus: $\frac{2}{1}$ – see Fig. 8d.

The first attestation of bar fractions more or less in the form we know them today[94] is in a treatise on arithmetic by Abū Zakariyā' al-Ḥaṣṣār, a 12th- or 13th-century scholar from the Muslim West. Little is known about the life of al-Ḥaṣṣār.[95] (Of course, other forms for fractions were used in earlier Islamic writings on arithmetic; indeed, "our" forms without

that is $43^1/_2°$ – see *Munich Astrolabe Catalogue*, no. 2, with illustration. On this form see also Cajori, *History of Mathematical Notations*, I, p. 311, after Cappelli, *Lexicon abbreviaturarum*, pp. LV and 408, mentioning the 13th century.

[91] On the back of #101, an astrolabe made in Iraq in the 10th century, the markings are all by a European. The solar and calendar scales are improperly constructed, and the very medieval-looking letters of the alphabet are mixed with 16th-century numeral forms on the scales. At the end of February we find $28^1/_4$. All of this engraving seems to be by a 19th-century faker. See further King, "Medieval Italian Non-Standard Astrolabe", §B7.

[92] No backs of standard Arsenius-type astrolabes are illustrated in Gunther, *Astrolabes*, and no fractions appear on those few shown in *Madrid 1997 Exhibition Catalogue*. Four such astrolabes with $^1/_4$ written "properly" are: #411, #439, #486 and #3016 (information kindly provided by Koenraad van Clempoel; these instruments are not listed in Appendix A).

[93] See the detailed description in García Franco, *Astrolabios en España*, pp. 229-235 (no. 12), especially p. 233. The same feature occurs on a newly-rediscovered 16th-century Spanish universal astrolabe #4561 – see Moreno *et al.*, "Spanish Astrolabe". Indeed, the markings on these two astrolabes may be by the same individual.

[94] On fractions in earlier numerical traditions see the various useful chapters in Benoit *et al.*, eds., *Histoire des fractions*. On the "discovery" of decimal fractions by al-Uqlīdisī in 10th-century Damascus see Berggren, *Episodes*, pp. 36-39, and Djebbar, "Fractions au Maghreb", pp. 225-230. See also Cajori, *Mathematical Notations*, I, pp. 309-314 (overview).

[95] Aballagh & Djebbar, "Découverte", especially pp. 149-150.

the bar may have appeared in India at the same time as the Indian numerals.[96]) al-Ḥaṣṣār's treatise was translated into Hebrew by Mōshē ben Ṭibbōn (1240-1275) in Montpellier in the year 1271.[97] This was one way in which fractions were introduced in Europe, but it was not the only way. For they appear already in the *Liber abbaci* (1228) on computation by Leonard of Pisa known as Fibonacci (b. *ca.* 1170, d. after 1240), who was well acquainted with Muslim sources, having worked in Bougie, now in Algeria, then a Pisan trading colony, and having studied there with Muslim scholars.[98] Several later Muslim writers use bar fractions.[99] Later European scholars using bar fractions are Jean de Linières (d. *ca.* 1350), Jean de Murs (14th century) and Nicole Oresme (1320-1382).[100]

We can be certain that the engraver was working in a milieu, probably very restricted geographically and temporally, where everyone wrote them with the denominator on the top and the numerator on the bottom.[101] No other attestations of fractions of this kind are known either from medieval Islamic or European sources.[102] Neither does there appear to be any Jewish/Hebrew influence in the form $\frac{2}{1}$.[103] We do find such fractions in China in the 17th century, prompted, however, by linguistic consid-

[96] Benoit *et al.*, eds., *Histoire des fractions*, p. 214.

[97] His treatise is translated in Suter, "Rechenbuch von al-Ḥaṣṣār". On the author see also Sarton, *IHS*, II:1, p. 400, and on his translator *ibid.*, II:2, p. 847-850.

[98] Article "Fibonacci" in *DSB*, especially pp. 604-606. The new English translation in Sigler, *Fibonacci's Liber Abaci*, is based on the 1857-62 edition of Boncompagni rather than on any of the numerous manuscripts.

[99] See Djebbar, "Fractions au Maghreb", and Aballagh, "Fractions chez Ibn al-Bannā'".

[100] Cajori, *Mathematical Notations*, I, pp. 91-93 (Oresme); and Tropfke, *Geschichte der Elementarmathematik*, pp. 108-114 (general).

[101] Compare the use of monastic numeral ciphers on the 14th-century Picard astrolabe #202 (see n. 41). The reason they were used for all numbers on the astrolabe was because the people for whom the astrolabe was intended, used or at least understood these ciphers. See King, *Ciphers of the Monks*, p. 141.

[102] See Allard, "Fractions dans les premières arithmétiques latines", and Benoit, "Arithmétiques commerciales françaises".

[103] See Lévy, "Fractions en hébreu".

erations: y *fen zhi* x, "x of y parts", for $\frac{x}{y}$.[104] Such considerations may be at work in the form $\frac{2}{1}$ on the astrolabe: the equivalent in English would be "(of) two parts one". Linguistic considerations apart, the notation is arbitrary: we write $\frac{3}{5}$ because we say "three fifths"; in a language in which people might say the equivalent of "fifths three", they might prefer to write $\frac{5}{3}$. Bar fractions caused some difficulty to the earliest printers in Europe, as we can see from the geographical tables in the Ulm, 1462 edition of Ptolemy's *Geography*, where the denominator of unit fractions is printed in the same font as the other numbers and a minuscule $\frac{1}{}$ printed above with varying amounts of success.[105] And on one of the 16th-century Louvain instruments mentioned above, namely #555 (unsigned and undated), the $\frac{1}{4}$ is actually engraved as '$\frac{4}{1}$' – see Fig. 11.[106] The use of an inverted fraction in the 16th century defies explanation![107] We also note that regular bar fractions in which the numerator is greater than the

[104] K. Chemla and C. Jami have drawn attention to a "similar" phenomenon in 17th-century China: see Chemla, "Fractions en Chine", especially pp. 190-191, and Jami, "Chinese and Western Arithmetics in the 17th Century", pp. 360-361.

[105] Illustrated in Peignot & Adamoff, *Chiffres*, p. 67. Even here a medieval form of the '5' is used. On the problems of printing fractions of the form $\frac{m}{n}$ and the predilection of printers for fractions in the form $^{m}/_{n}$ (using the "*solidus*", that is '/') see Cajori, *Mathematical Notations*, I, pp. 312-314.

[106] See *Nuremberg GNM 1992-93 Exhibition Catalogue*, p. 599 and fig. 1.82.7, with the remark "gerade solche Details könnten bei der Analyse anderer Arsenius-Astrolabien oder verwandter Instrumente weiterhelfen", that is, "precisely such details (as this inverted fraction) could be useful for further analysis of Arsenius astrolabes and related instruments"!

[107] There is no trace of this phenomenon in the extracts from early printed works on arithmetic surveyed in Smith, *Rara arithmetica*. For bar fractions using Roman numerals in an early-16th-century German arithmetic see *ibid*., pp. 105 and 106.
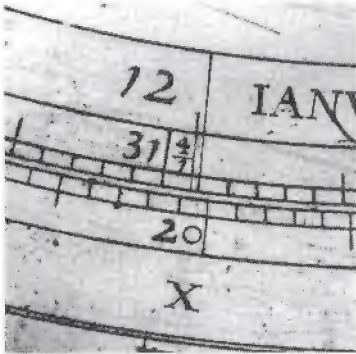
Fig. 11 The fraction 1/4 engraved as '$\frac{4}{1}$' on the calendar scale of an unsigned astrolabe from 16th-century Louvain (#555). [Photo by the author, courtesy of the Germanisches Nationalmuseum, Nuremberg.]

denominator were known in the Middle Ages and are still in very occasional use today.[108]

In the future it may be possible to locate other relevant historical sources in which fractions are inverted. In Spain even in the 15th century entries in some astronomical tables were written sexagesimally in Roman numerals,[109] although the *Alfonsine Tables* corpus used Hindu-Arabic numerals.[110] Arithmetic there in the late Middle Ages seems to have been dominated by the Latin tradition of al-Khwārizmī,[111] in which the Hindu-Arabic forms are introduced but Roman numerals are used throughout the text. We shall thus have to look elsewhere for such attestations:

[108] Note the forms (n+p)/n or (2n+p)/n relating to music theory in a Mozarab manuscript of the *Arithmetic* of Boethius (d. *ca.* 525 – see *DSB*), datable to the 10th or early 11th century – see Millás Vallicrosa, *Assaig*, pp. 91-92, also cited in Vera, *MME*, p. 80.

In passing we note the following remark in Singmaster, "Mathematical Gazetteer of Britain", p. 16:

"Near Harrowgate station is a hairdresser's named 'Twenty Two over Seven'. The owner is a Polish refugee with a long name like Pychovski which was simplified to Pye (?). As a result he tried to name his business 'Π', but the local council, telephone company, etc., couldn't deal with a name using a Greek letter. He then tried to name it '22/7' but had the same problem, so he had to spell out the numbers. His shop window has 'Π', '22/7' and 'twenty two over seven' all painted on it."

[109] See Chabàs & Roca, *Lunari de Bernat de Granollachs*, and Cátedra & Samsó, *Astrología de Enrique de Villena*.

[110] Illustrated in *Cádiz-Algeciras 1995 Exhibition Catalogue*, p. 266.

[111] See, most recently, Folkerts & Kunitzsch, "al-Khwārizmī".

financial accounts,[112] weights and measures,[113] tide-tables,[114] and the like. Preliminary investigations in these areas have borne no fruit. But it is clear that we are dealing here with a development independent of the Khwārizmī – Ḥaṣṣār / Ben Ṭibbōn – Fibonacci traditions.[115] There were other short-lived independent traditions: one 14th-century manuscript of unidentified provenance uses a convention in which three-fifths is written $3\ \bar{5}$, *etc.*[116] To put it another way, there is no reason why a European in Central or Northern Spain in the 14th century should have written the latitude of Jerusalem as $32\frac{1}{2}$ rather than $32\frac{2}{1}$. Fibonacci would have written it as $\frac{1}{2}32$ anyway.[117]

[112] An equivalent to Benoit, "Arithmétiques commerciales françaises", for the Hindu-Arabic numerals in Spain would be useful. But see n. 115 below.

[113] See, for example, Kisch, *Scales and Weights*, a useful work but deficient on Spanish materials. I have not yet consulted Mateu y Llopis, *Ponderales monetarios*.

[114] See Howse, "Early Tidal Diagrams", where unusual numeral forms do occur.

[115] Other independent, mainly regional, developments in medieval Spain are noted in Labarta & Barceló, *Números y cifras*, where there is, alas, no mention of inverted fractions.

[116] Eneström, "Bezeichnung von Brüchen", citing MS Vatican Ottob. 399 of a medieval Latin treatise, undated but from before 1350. Eneström concludes his note with the remark:

"Vielleicht gab es im christlichen Mittelalter noch andere Weisen, die gewöhnlichen Brüche zu bezeichnen, und für die Geschichte der mathematischen Sprache wäre jedenfalls eine nähere Untersuchung der Frage von Interesse."

This unusual variety of fraction is also mentioned in Cajori, *Mathematical Notations*, I, p. 311.

[117] *Ibid.*: "Leonardo read from right to left, as did the Arabs ... . In the case of a mixed number, like $3\ ^{1}/_{5}$, Leonardo and the Arabs placed the integer to the right of the fraction."

f) *The Arabic engraving*

All of the principal Arabic inscriptions are in *naskhī* script,[118] which at first might be taken as clear evidence that their engraver was neither an Andalusī nor a Maghribī. Rather, they are what one would expect of a Syrian or Egyptian engraver. The use of regular *naskhī* script in the engraving of early Islamic astrolabes is rare; usually Kufic script or ornamental *naskhī* script was preferred. But already in the 13th century, at least in Egypt, we find regular *naskhī* script used on an astronomical instrument – see #107, an astrolabic plate made by Ḥasan ibn 'Alī in Cairo in 681 H [= 1282/83].[119]

Yet *naskhī* script was used in some Andalusī inscriptions in the 13th-15th centuries, in particular in a series of 14th-century poetic inscriptions in the Alhambra in Granada.[120] Likewise *naskhī* script is used on an ivory box from 14th-century Spain, which was previously thought to have been Egyptian.[121] Nevertheless, no other astronomical instruments engraved in *naskhī* script are known from al-Andalus.

The Arabic on the boss of the shackle, the rete and the back are all by the same person. One may note the distinctive form of the solitary (*i.e.* initial or final unconnected) *d* (= *dāl*), with a curved inward hook at the lower extremity.[122] This form is found, for example, on the boss, in the

[118] On Arabic scripts see the article "Khaṭṭ" [= script] in *EI*₂, and Schimmel, *Islamic Calligraphy*.

[119] It has been suggested that the maker was the Cairo astronomer of Maghribī origin, Abū 'Alī al-Ḥasan ibn 'Alī al-Marrākushī – see the article "al-Marrākushī" in *EI*₂.

[120] On the emergence of *naskhī* in Andalusī inscriptions in the 14th century see Fernández-Puertas, "Calligraphy in Al-Andalus", pp. 663-665, and also pl. III.9, as well as the title-page of Gabrieli, ed., *L'Islam en Europe*, for one of the inscriptions in the Alhambra, amply provided with *sukūn*s and vowels. See also Welch, *Muslim Calligraphy*, p. 72, no. 17, for a 14th- or 15th-century terracotta font from Muslim Spain, also with decorative *naskhī* script in oblong cartouches.

[121] Featured in *Venice 1993-94 Exhibition Catalogue*, pp. 115-116 (no. 32). The inscription exhibits some curious orthographical features and is decorated with what look like *sukūn*s all over the place.

[122] Arabic letters can have up to four different forms, depending on whether they stand alone or at the beginning, middle or end of a word.

name *Mas'ūd*; on the rete, in the star-name ***dab(a)rān***; and on the back, in the name ***dvjvnbvr*** for December (where *v* is any vowel). It is a classical calligraphic form,[123] and is also found on the Alhambra inscriptions and the ivory box mentioned above. Also a small number of the letters in the Arabic inscriptions are repeated in miniature above the actual letter, like the *d* in the name *al-asa**d*** on the ecliptic scale on the back and the *k* (= *kāf*) in *al-mali**k*** on the boss of the shackle. This practice is unusual but it is not "wrong".[124] The criss-cross decoration so prominent in the inscriptions on the back is also found in the inscription on the boss of the shackle, under the letters *m-s-* in the name Mas'ūd.

The forms of the month-names are entirely within the Western Islamic tradition. There is only one error, which is probably not significant: one dot has been omitted on the *y* (= *yā'*) in the word *fabrāyir*, making it read *fabrābir*.

The secondary Arabic inscriptions, the star-names scratched on the rete, are in a distinctive hand, quite different from that of Mas'ūd. In particular we note the downward stroke for the final *d* (= *dāl*) on *asad* (for Leo), rather like a final *n* (= *nūn*) in written cursive Hebrew, and the forward (towards the right) sloping vertical stroke of *ṭ* (= *ṭā'*). This is a typical Andalusī or Maghribī phenomenon.

An only partly successful attempt has been made to scrape off the Latin name of the star 9OR S9ORPI on the upper right of the circumferential frame of the rete. Presumably the person who added the second layer of Arabic star-names did this and then gave up trying to remove the remaining inscriptions. On various early Islamic astrolabes we can see similar attempts by Europeans to remove the Arabic inscriptions

[123] Schimmel, *Islamic Calligraphy*, p. 18.

[124] See Lings, *Quranic Calligraphy and Illumination*, pl. 28, on a *Qur'ān* from late 13th-century Baghdad in which most of the letters ' (*'ayn*), *ṣ* (*ṣād*) and *ṭ* (*ṭā'*) have a minuscule letter repeated below and the final *k* (*kāf*) above. Other examples are to be found *ibid*., pls. 41, 51 and 57. The purpose here seems to be to distinguish the letters from the three corresponding letters with a dot: <u>gh</u> (<u>gh</u>*ayn*), *ḍ* (*ḍād*) and *ẓ* (*ẓā'*). The repetition of the *k* is particularly common in Arabic calligraphy, to distinguish the letter from the final *l* (*lām*). This phenomenon is not to be confused with the use of small letters above words in the *Qur'ān* as a guide to recitation, marking, for example, pauses.

and replace them with Latin ones – for example, #110[125] and #1077.[126] On one medieval European astrolabe (#460), from the Fusoris workshop in Paris *ca.* 1400, some of the inscriptions have been removed and replaced by Arabic ones in a Syrian or Egyptian hand, probably as late as the 19th century; there are no changes to the calendrical scale on the back which could have identified the location of these modifications more closely.

g) The size of the astrolabe

The diameter of this astrolabe is 133 mm, which may be characterised as average when compared with the diameters of the four medieval astrolabes from Catalonia and the one astrolabe with Judaeo-Arabic inscriptions:

#3042, late 10th-century:	154 mm
#162, *ca.* 1300:	100
#416, *ca.* 1300:	147
#3053, Barcelona, 1375:	109
#3915, Judaeo-Arabic, *ca.* 1300:	185

No other early medieval European astrolabes have diameter 133 ± 2 mm, except #291, an English piece dated 1326, which has 134 mm.[127]

h) The throne

The arabesque decoration[128] of the throne is most unusual for Western Islamic astrolabes and early European astrolabes. It might be thought that this throne shows distinct Syrian influence.[129] However, an Andalusī

[125] See Gunther, *Astrolabes*, I, p. 244 (no. 110), and King, "Earliest European Astrolabe", fig. 3.

[126] Maier, "Romanische Monatsnamen", B, pp. 261-262.

[127] See Price *et al.*, *Astrolabe Checklist*, pp. 44 and 78.

[128] See the article "Arabesque" in EI_2.

[129] We may compare the thrones on #140, the universal astrolabe of Ibn al-Sarrāj, made in Aleppo in 1328/29, and #106, a universal plate made in Cairo (?, the calendar scale has

astrolabe made in 638 H [= 1240/41] (#154) has a throne that is almost identical, if less elegantly worked – see Fig. 10.[130] A simpler, but not dissimilar design, is also found on #4182, made in Fez in 719 H [= 1319/20] by a maker whose family, if not he himself, hailed from Cordova – see Fig. 12. Thus it is not necessary to suppose any direct Syrian influence. The individual elements of the throne are found on other Andalusī pierced metalwork, as, for example, a spectacular lamp made in the royal workshops of the Naṣrid court at Granada for the mosque of the Alhambra in 705 H [= 1305/06], now in the Museo Arqueológico Nacional in Madrid.[131]

The shackle is more European than Islamic, the closest being that on #416, from Catalonia *ca.* 1300, on which the boss, however, is radially ribbed outside the circular central part.[132]

i) The basic form of the rete

The design is mainly, if not fully, Islamic in conception. In other words, the quatrefoil decoration within the ecliptic, the form of the star-pointers, the small circle at the bottom of the rete, and the counter-changing of the horizontal diameter are Islamic.

the Coptic months) in 1299/1300 by Ibrāhīm al-Dimashqī. See also n. 212 below. This kind of arabesque decoration on thrones is exaggerated on #109, made by the Yemeni Sultan al-Ashraf in 1291.

[130] As stated in n. 15 above, this piece is misdated to 1747 in Gunther, *Astrolabes*, I, p. 300. The Hijra date is written *kh-l-ḥ*, that is, 638.

[131] See *Granada-New York 1992 Exhibition Catalogue*, pp. 276-277 (no. 57).

[132] The shackle on #134, decorated with a lion's head, is not necessarily original to this Andalusī astrolabe datable *ca.* 1220. Likewise, the shackle on #154, made in al-Andalus in 1240/41, on which the throne has the same form as that on the astrolabe under discussion, is different in design. On the other hand, the shackle on #162, from Catalonia *ca.* 1300, is rather similar.

Fig 12a The distinctive rete and distinctive throne on an astrolabe made in Fez in 1319/20 by Muḥammad ibn Qāsim al-Qurṭubī (#4182). Neither rete nor throne bears any relationship to any other Maghribī astrolabe. Since the maker or his family came from Cordova it seems that we are dealing with a piece that reflects Andalusī influence.

Fig. 12b The back of the same instrument. This is the only known Islamic astrolabe with a quatrefoil cartouche, again probably indicative of Andalusī influence.

Fig. 12c Detail of the barbed quatrefoil around the inscription on the back. [Present location unknown, photos from the archives of the late Alain Brieux, courtesy of Dominique Brieux, Paris.]

The three half-quatrefoils inside the ecliptic ring are not attested amongst the numerous varieties of quatrefoil decoration on European astrolabes, which might seem to imply some European input here. But the quatrefoil was a feature of the design of certain Byzantine and early Islamic astrolabe retes, and it is found on some early European retes. Certainly no Islamic retes are known with half-quatrefoils. Yet here the half-quatrefoil frames perform their original function as supports for star-pointers, whereas on later European retes the quatrefoils are more often merely decorative. This may be taken as additional evidence that even the quatrefoil design used here is entirely Islamic in conception.[133] For example, that the "Gothic" quatrefoil design on #162, a Catalan astrolabe from *ca.* 1300, is copied entirely from an Islamic rete, the design being partly Eastern Islamic (and therefore Byzantine in origin), namely, the quatrefoil, and the rectangular frame which it decorates being Western Islamic.[134] As confirmation of the latter we may invoke #3915, the Maghribī or Andalusī astrolabe from *ca.* 1300 with inscriptions in Judaeo-Arabic: this has a slightly less elegant form of the rectangular frame and a degenerate quatrefoil.[135] In other words, the retes on both #162 and #3915 were copied from a rete on a Western Islamic astrolabe of which no examples survive. As proof of how little we know about the design of Western Islamic astrolabes between *ca.* 1100 and *ca.* 1300 we need only cite #154, made somewhere in al-Andalus in 638 H [= 1240/41], having two larger decorative quatrefoils on the rete – see Fig. 10.[136]

The half-quatrefoils on the short bars connecting the ecliptic ring to the outer frame on the astrolabe under discussion also merit further comment. The idea is Islamic, because we find a *miḥrāb*-shaped design in the same position on the 11th-century Toledo astrolabe #117, and a similar "half-quatrefoil"-type design, albeit with a not quite rounded middle arc, on #4182, an astrolabe made in Fez in 719 H [= 1319/20] by an Arab Muslim

[133] On quatrefoil decoration on astrolabes in general see King, *Ciphers of the Monks*, pp. 380-390.

[134] King & Maier, "Catalan Astrolabe", pp. 679-683; and King, *op. cit.*, pp. 382 and 387.

[135] King & Maier, *op. cit.*, pp. 681; and King, *op. cit.*, p. 382.

[136] *Ibid.*, pp. 382 and 386.

whose family origins were in Cordova; this shows not a trace of European influence – see Fig. 12. Similar bars are found on #162 from Catalonia *ca.* 1300, and a like decoration is found on the supports of the lower equatorial ring on #300, possibly of Northern French origin and also datable to *ca.* 1300 – see Fig. 13.
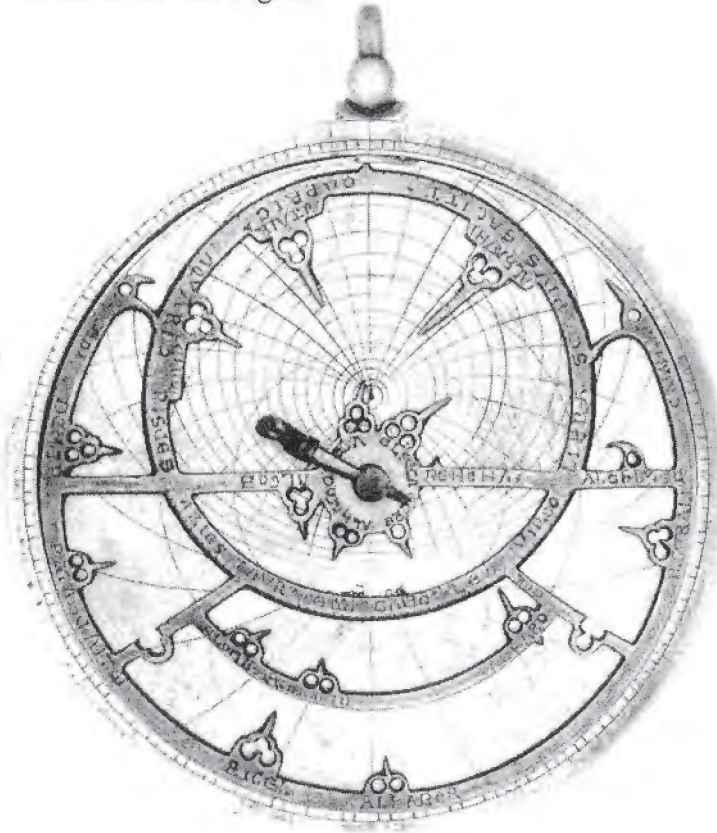
Fig. 13 The front of an astrolabe (#300) with half-quatrefoil insets on the frames supporting the lower equatorial bar, and with star-pointers that bear some resemblance to those on the Spanish astrolabe under discussion (see §3k). [Courtesy of the Museum of the History of Science, Oxford.]

The counter-changes on the horizontal bar are shown here in an exaggerated schematic form:

This arrangement is found on seven 11th-century Andalusī astrolabes (including #1099),[137] and some later, but still early European instruments (#428 from France; #191, a composite piece of uncertain origin(s), but with rete possibly reworked from an Andalusī one; and #558 of uncertain provenance).

A small circle similar to the one at the bottom of this rete is found already on 11th-century Andalusī astrolabes (such as #116 and #123) and on some of the astrolabes of al-Khamā'irī of Seville *ca.* 1220 (such as #130, #139 and #153), as well as on #4182, made in Fez *ca.* 1320. On the Andalusī piece #154, dated 638 H [= 1240/41], this circle is replaced by a quatrefoil, which may have been the original design. Only on one other European astrolabe, #420, a very early piece of uncertain provenance (*ca.* 1200, if not earlier), does this small circle reappear. However, it also features on the astrolabe illustrated in the 13th-century *Libros del saber de astronomía* of Alfonso X.[138]

The four "cardinally-aligned" handles in the form of silver knobs are situated near the extremities of the horizontal bar (the one on the left is missing), at the top of the rete, and above the small circular frame. The same arrangement is found on some 11th-century Andalusī astrolabes (such as #116, #123 and #2527) and various astrolabes of al-Khamā'irī of

[137] For more details see King, "Earliest European Astrolabe", pp. 367-369. The two earlier Andalusī astrolabes, #110 and #4024, have simpler (single) counter-changes, which is already a development beyond the straight bars on the earliest Eastern Islamic astrolabes.

[138] Reproduced in *Santa Cruz 1985 Exhibition Catalogue*, p. 25; and *Cádiz-Algeciras 1995 Exhibition Catalogue*, p. 171.

Seville *ca.* 1220 (such as #130 and #139). However, it is not found on any of the other early European astrolabes, possibly because many of them have radial rules attached to the front.

j) Observations on the quatrefoil

The quatrefoil, one of the most distinctive motifs of medieval European art and decorative architecture, is generally regarded as little more than that. It is true that quatrefoils are found, for example, on some early Anglo-Saxon artefacts; however, the origin of the quatrefoil as one of the principal motifs in late medieval Christian art is to be sought in Byzantine art, transmitted from Syria to al-Andalus. It is an important motif of Andalusī decorative art, albeit usually not independent of other designs (in other words, connected to other designs) and often developed beyond the simplest form.[139] A design including rounded quatrefoils, with rounded half-quatrefoils forming part of the surrounding frame, is found on a sockel of the Peinador Bajo in the Alhambra.[140] This is a rare use of half-quatrefoils, and corresponds precisely to their use on the rete of the astrolabe under discussion.

Now, as already noted, the quatrefoil also featured as a motif on Byzantine astrolabes, and this motif was incorporated on some of the earliest astrolabes from the Islamic East.[141] Somehow the same motif came to appear on some of the earliest astrolabes in Islamic Spain. The earliest known example is #154 from *ca.* 1240, with two fully developed

[139] For decorative art in Andalusī architecture the best study is Pavón Maldonado, *El arte hispanomusulman*. On the quatrefoil and variations thereon see *ibid.*, pp. 69-75, and figs. 98, 102, 104 (no. 23), and pls XLIIb and CLXII (Alcázar, Seville), CLXXIV (Casa de Pilatos, Seville), and CLXXXIV (Madīnat al-Zahrā').

[140] *Ibid.*, fig. 98.

[141] See King, "Kuwait Astrolabes", pp. 80 and 82-89, especially p. 85, on the quatrefoil on the rete of the magnificent astrolabe of the astronomer-mathematician al-Khujandī (#111), made in Baghdad in 984/85; *idem* & Maier, "Catalan Astrolabe", pp. 680-682, on the quatrefoil on the Catalan piece #162; and *idem*, "Astronomical Instruments between East and West", pp. 154 and 169, on some other examples. These instruments are also illustrated in King, *Ciphers of the Monks*, pp. 384-390. The four papers listed as Tomba, "Astrolabi", A-D, deal with various Italian astrolabes with quatrefoil decoration.

quatrefoils, but this is alas the only example! It simply shows how little we know about this development. We have already noted the half-quatrefoils on the bars between the ecliptic and circumferential frame on #4182, made in Fez *ca.* 1320; a barbed quatrefoil is used to frame the inscription on the back of this piece: see Figs. 12 b-c. The quatrefoil motif was copied on a subgroup of early European astrolabes, notably #162 and the astrolabe under discussion. The Europeans developed the quatrefoil as a decorative feature on astrolabe retes far more than the Muslims had done – see, for a spectacular example, #290, made in England *ca.* 1300. Also Jewish craftsmen used the quatrefoil, even cruciform quatrefoils, as decoration on astrolabes.[142] Even the pre-expulsion seals of the Jews in Christian Spain were often in the form of, or had decoration in the form of, quatrefoils.[143] We shall return in §3z to the quatrefoil decoration of the cartouches on the back of the astrolabe under discussion.

k) The form of the star-pointers

Identical star-pointers are not found on any known astrolabe, Andalusī or medieval European. Those that come closest are found on the Northern French (?) astrolabe #300 from *ca.* 1300 (see Fig. 13), but they have larger holes, either single, double or triple, depending on the size of the pointer.[144]

l) The positions of the star-pointers

The position of Regulus, which being on the ecliptic serves as an indicator of precession and hence the date, is at Leo 22°, corresponding to *ca.* 1425.

[142] King, "Astronomical Instruments between East and West", pl. VIa on p. 154.

[143] See Friedenberg, "Spanish Jewish Seals", and the earlier publication by the same author, for various examples. Another is shown in *New York JM 1992 Exhibition Catalogue*, pp. 240-241 (no. 98).

[144] See Gunther, *Astrolabes*, II, pp. 477-478 (no. 300), and also G. Turner, "Carolingian Astrolabe", fig. 5 before p. 431.

But this is insufficient to date the piece. The remaining star-positions point to a date in the range 1300-1350.[145]

m) The selection of stars

There are some 21 star-pointers. Western Islamic astrolabes tend to have some 27, following a clearly-defined tradition associated with the astronomer Maslama al-Majrīṭī (Madrid, *ca.* 1000).[146] The earliest known European astrolabe, #3042 from 10th-century Catalonia, has 20 unlabelled pointers,[147] and the astrolabe under discussion has 19 of these but is missing α Ophiuchi (often named *alhawi* on medieval European astrolabes) and has in addition RIGORCA and ON9E. The Catalan astrolabe #162 from *ca.* 1300 has 20 stars, of which three are not found on this astrolabe.[148] A second star-table of al-Majrīṭī contains precisely 21 stars but only 13 of these are found on this piece.[149]

It is not unusual that the *selection* of stars represented on medieval astrolabes does not correspond to the various textual traditions that have been discussed by Paul Kunitzsch, and there is a lot more research remaining to be done on the data from instruments.[150]

n) The Latin names of the stars

The names of the stars on the rete are mainly Europeanised versions of the Arabic names, as was standard in the Middle Ages.[151] There are also

[145] Information kindly provided by Burkhard Stautz.

[146] Kunitzsch, *Typen von Sternverzeichnissen*, pp. 17-18 (Typ III); and *idem* & Dekker, "Stars on the Carolingian Astrolabe", pp. 656-658. On Maslama see the article "al-Madjrīṭī" in EI_2.

[147] Kunitzsch & Dekker, "Stars on Carolingian Astrolabe", *passim*.

[148] King & Maier, "Catalan Astrolabe", pp. 676-677 and 684-685.

[149] Kunitzsch, *Typen von Sternverzeichnissen*, pp. 15-18.

[150] See the problems discussed already in King & Maier, "Catalan Astrolabe", pp. 684-685.

[151] On these see the numerous publications of Paul Kunitzsch. The forms found on astrolabes have not yet been subjected to serious study, but at least are documented in the

several examples of Latin names, which we can associate with the introduction of the Latin translation of the *Almagest* of Ptolemy in al-Andalus in the 12th century.[152] But there are also four examples of bastardised Latin names, as if dictated by someone who could not read them properly; this is most unusual, but not entirely without precedent. It is certainly not unusual that the *names* actually used on astrolabe retes do not correspond to the names known from textual sources.[153]

There are some 21 star-pointers, and the stars seem to have been taken – appropriately enough – from the catalogue associated with the celebrated translator Johannes Hispalensis (Toledo, mid 12th century),[154] that is, Paul Kunitzsch's "Typ IV".[155] At least, all of the stars but one in Pegasus are found in his catalogue.[156] In this the Latin names of 29 stars are presented, and Kunitzsch has suggested that the star-names may have been translated from those on an Andalusī astrolabe.[157]

The following table presents the original "Latin" names of the stars, with their numbers in Paul Kunitzsch's lists of astrolabe-stars,[158] the

forthcoming Frankfurt catalogue (n. 13 above). On the star-names on this piece see already King, "Star-Names on Three European Astrolabes", pp. 308-316.

[152] On Ptolemy see the article in *DSB*. For editions of the Arabic and Latin versions of his star catalogue see Kunitzsch, *Sternkatalog des Almagest*. See also Kunitzsch, *Typen von Sternverzeichnissen*, pp. 16-17, for a 12th-century list in which selected stars are already labelled in Latin.

[153] One needs only to compare the names found on any medieval astrolabe with those presented in the index to Kunitzsch, *Typen von Sternverzeichnissen*.

[154] See Sarton, *IHS*, II:1, pp. 169-172.

[155] Kunitzsch, *Typen von Sternverzeichnissen*, pp. 31-33.

[156] I refer to ε Pegasi, and there is also seems to be a problem with α and β Pegasi.

[157] *Ibid.*, p. 31. On the 27 astrolabe stars in the tradition associated with Maslama al-Majrīṭī (Madrid, *ca.* 1000) see n. 146 above. The star-tables associated with Ibn al-Zarqālluh – see Kunitzsch, "Two Star Tables from Muslim Spain" – do not have the enigmatic star *ka'b al-faras* in Pegasus.

[158] The first number relates to the list in Kunitzsch, "Astrolabe Stars", pp. 158-161, representing the main Islamic tradition associated with the 10th-century Shiraz astronomer al-Ṣūfī (on whom see the article in *DSB*), and the second to the list in *idem*,

Arabic additions (in two layers), the Arabic or Latin forms from which these are derived, the number in Kunitzsch's "Typ IV", as well as the identification of the star and its modern designation.[159] I do not give the Latin names in the single 13th-century Vienna manuscript used by Kunitzsch in his edition of the table of "Typ IV". There is a 14th-century copy in Oxford in which the Arabic equivalents are given alongside the Latin names,[160] but none of these lists casts any light on the problems associated with the names on our rete, which do not correspond to those in Kunitzsch's "Typ IV" anyway.

Arabische Sternnamen in Europa, pp. 59-96, where their subsequent fate in the Latin European textual tradition is documented.

[159] For an overview of the origins of modern star-names see Kunitzsch & Smart, *Star-Names*.

[160] A photo is to be found in Gunther, *Early Science in Oxford*, II, p. 205.

The stars featured on the astrolabe #4560

No.	K-no.	Star-name	Arabic additions (bold if original)	Arabic/Latin name (A/L) (as relevant)	K Type IV	Modern name	Designation
1	50/8	**PANTA 9AITOS**	*baṭn* • (illegible letter)	A *baṭn qayṭus*	1	Baten Kaitos	ζ Ceti
•		dummy pointer (support symmetrically placed to the pointer for COR LEONIS (no. 7 below), as on various Western Islamic astrolabes)					
2	9/14	**ALGOL**	*ghūl*	A *al-ghūl*	2	Algol	β Persei
3	24/18	**D**(A)**B**(A)**RAN**	***dabrān***	A *al-dabarān*	3	Aldebaran	α Tauri
4	37/19	**RIGEL**	*rijl al-jawzā*	A *rijl (al-jawzâ')*	6	Rigel	β Orionis
----------							
5	39/23	**ALABOR**	*'abūr*	A *al-'abūr*	8	Sirius	α Canis maioris
6	40/25	**9OMIZA**	***ghumayṣa***	A *al-ghumayṣâ'*	9	Gomeisa	α Canis minoris
7	26/30	**9OR LEO**(NIS)	*asad*	L *cor leonis*	12	Regulus	α Leonis
8	- /28	**RIGORCA**	*rijl*	A *rijl* + L *ursae* (!!)	10	-	μ Ursae maioris
9	43/36	**9ORUUS**	*ghurāb*	L *corvus*	14 (see text)	-	γ Corvi

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10	29/39	**SPI9A**	*a'zal*	L *spica*	15	Spica	α Virginis
11	1/41	**ALRAME**(CH)	illegible	A *(al-simāk) al-rāmiḥ*	17	Arcturus	α Boötis
12	2/45	**FE9A**	*fakka*	A *(al-)fakka*	18	Alphecca	α Coronae borealis
13	12/- (!)	**ON9E**	***al-ḥayya***	A *'unuq al-ḥayy*	19	Unukalhai	α Serpentis
14	30/48	**9OR S9ORPI**(ONIS)	*qalb*	L *cor scorpionis* A *qalb al-'aqrab*	20	Antares	α Scorpionis
----------							
15	4/53	**UEGA**	*wāqi'*	A *(al-nasr) al-wāqi'*	22	Vega	α Lyrae
16	6/56	**RADF**	*rid[f]*	A *(al-)ridf*	25	Deneb	α Cygni
17	13/54	**ALTAIR**	***al-ṭāyir***	A *(al-nasr) al-ṭā'ir*	24	Altair	α Aquilae
18	32/59	**9AUD:9OARI** (error for CAUD(A) CAPRI)	*ṭ-r-w* (??)	L *cauda capricorni*	26	Algedi	δ Capricorni
19	- / -	**9ABI**	- (!)	A *ka'b a(l-faras)*	-	-	κ Pegasi
20	18/63	**OMER9I**	*mankib faras*	L *(h)umerus equi*	27 (β Peg)	Scheat	α Pegasi
21	35/4	**D(E)N(E)P 9AITOS**:	*d̲(h̲anab)*	A *d̲h̲anab qayṭus*	29	Deneb Kaitos	ι Ceti

Some comments on the more unusual names are in order. (See already the remarks in §3c on vernacular influences.) Firstly, some forms derived from the Arabic:

PANTA (no. 1) from *baṭn*, "belly (of the whale)". This form is found already in a 10th/11th-century Latin source, as well as in a 13th-century copy of the astrolabe treatise of Pseudo-Messahalla, parts of which are translated from a treatise by the Andalusī astronomer Maslama al-Majrīṭī.[161]

D(E)N(E)P / D(A)N(A)P (no. 21) from *dhanab*, "tail (of the whale)". The more usual form is DENE**B**.[162]

9OMIZA (no. 6) from *(al-)ghumayṣā'*, which means something like "the one with eyes impaired by weeping" (compared with Sirius). This form is not attested in the manuscript tradition, which tends to prefer (AL)GOMEI/YZ/SA.[163] #162 has ALGOMIC.

ON9E (no. 13), a very vernacular derivation from *'unq* or *'unuq (al-ḥayya)*, "neck (of the serpent)", is not known to be attested elsewhere. The early modern (17th-century) forms are UNUK or UNK, usually followed by ALHAY or variants thereof, which are closer to the Arabic.[164] The .final E of ON9E is probably a remnant of the Arabic article *al-*.

UEGA (no. 15) from *(al-)wāqi'*, "falling (eagle)". This corresponds to WEGA in some textual sources.[165]

RADF (no. 16) from *(al-)ridf*, "the person riding on a horse behind the main rider", is not known either from the textual tradition or from any known medieval astrolabe. The more common names

[161] See Kunitzsch, *Arabische Sternnamen*, p. 67, no. 8.

[162] *Ibid.*, p. 66, no. 4.

[163] *Ibid.*, pp. 73-74, no. 25.

[164] *Ibid.*, p. 217, no. 196. For some reason this star is not listed by Kunitzsch as an astrolabe-star.

[165] *Ibid.*, p. 81, no. 53.

are RIDF and REDF, corresponding more closely to the Arabic,[166] and #162 has ALREDAF.

9ABI (no. 19), pronounced KABI, appears to be derived from the Arabic *ka'b al-faras*, "the ankle of the horse (Pegasus)", κ Pegasi. This star is not otherwise known from European astrolabes or star-lists. Indeed it is not a standard astrolabe-star, although it does appear on some of the astrolabes of the prolific Muḥammad ibn Fattūḥ al-Khamā'irī of Seville *ca.* 1225.[167]

Then some forms based on Latin:

9AUD: 9OARI (no. 18) is an error for CAUD(A) CAPRI-(CORNI), with COARI apparently from ACOARI (from Aquarii),[168] rather than from CAPRI. The colon is used as a separator (also at the end of no. 21); it was not uncommon for abbreviations such as HU: EQUI (for HUMERUS EQUI – see below) to be used for star-names engraved in restricted space on astrolabe retes.

OMER9I (no. 20), pronounced OMERQ(U)I / OMERKI, seems to derive from OMER (E)QUI, a vernacular form of the Latin *humerus equi*, "the shoulder of the horse", α Pegasi.

Finally, one very remarkable name that seems to be based on a mixture of Arabic and Latin:

RIGORCA (no. 8), pronounced RIGORSA or RIGORÇA, may be from RIG(EL) ORSA(E), a combination of Arabic and vernacular Latin ("correctly", *rijl ursae*), μ Ursae maioris.[169] The proper Arabic form would be *rijl al-dubb*, "the (back) leg of the

[166] *Ibid.*, p. 82, no. 56.

[167] For example, on #130 – see Gunther, *Astrolabes*, I, pp. 276-277 (no. 130), and Kunitzsch, *Typen von Sternverzeichnissen*, p. 31, n. 2. On al-Khamā'irī see Mayer, *Islamic Astrolabists*, pp. 64-66.

[168] Aquarius does not, of course, have a tail (*cauda*), though see Burnett, *Studies*, XVII, p. 120, where he is given a *cadacauda* in a 12th-century source.

[169] *Ibid.*, pp. 74-75, no. 28.

Bear". The precise Latin equivalent is not specifically stated in the Latin translation of Ptolemy's star-catalogue,[170] and medieval European astrolabists seem to have had some problems with the star.[171]

o) The Arabic names of the stars

With regard to the four Arabic star-names added by Mas'ūd, we note the following:

dabrān (no. 3) with a *sukūn* or zero-vowel on the *r* (= *rā'*), clearly intended for the *b* (*bā'*); the standard name is *(al-)dabarān*.[172] This form *dabrān* is Spanish Arabic, for there the second vowel of two successive internal short syllables can be suppressed.[173] The usual medieval European forms are ALDEBARAN/M, although the astrolabe under discussion has DBRAN, perhaps for D(A/E)BRAN, perhaps for D(A/E)B(A)RAN, and ALDEBRAN is attested in Geoffrey Chaucer's treatise on the astrolabe and on one 14th-century English astrolabe (#457).[174]

ghumayṣa (no. 6), correctly *ghumayṣā'*, from which the Latin form is derived, is the Western Islamic name, the star being called

[170] See Kunitzsch, *Sternkatalog des Almagest*, II, p. 38, no. 21.

[171] It is not amongst Paul Kunitzsch's list of astrolabe stars (*Arabische Sternnamen in Europa*, pp. 59-96), but is listed as *pes ursi* (*sic*) in one medieval star-table (*idem*, *Typen von Sternverzeichnissen*, p. 32, no. 13). See also *Chicago AP Catalogue*, I, p. 159, where it is not to be found in the list of all stars featured on the astrolabes in the collection. On this star see now Kunitzsch, "Three Dubious Stars", pp. 68-69.

[172] Kunitzsch, *Sternnomenklatur der Araber*, p. 51, no. 69.

[173] Article "al-Andalus, x: Spanish Arabic" in EI_2, by G. S. Colin, especially p. 502b. I did not find any examples of this phenomenon in Corriente, *Spanish Arabic*, but words of the form CaCaCān are not common. On the other hand Corriente (*ibid.*, p. 64) notes that in an open syllable followed by a closed one the second vowel is stressed. In passing we note the form Çuléyman for Sulaymān (*ibid.*, p. 65).

[174] Kunitzsch, *Arabische Sternnamen in Europa*, p. 47 and p. 70, no. 18.

> *al-shiʿrā al-shaʾāmiya* in the Islamic East.[175] The form *ghumayṣa* is probably to be regarded as a Spanish Arabic simplification of the classical form.
>
> *al-ḥayya* (no. 13), with a *sukūn* on the *l* (= *lām*), which is correct but superfluous, and a *shadda* on the *y* (= *yā'*), which is appropriate, is abbreviated from *'unuq al-ḥayya.*[176]
>
> *al-ṭāyir* (no. 17), with a *y* (= *yā'*) rather than a carrier for a *hamza*, an acceptable Middle Arabic form of *al-ṭā'ir.*[177]

Note that the stars have been selected because each one is in a different quadrant of the heavens, so that at night, in theory, at least one is always visible. Another astrolabe (#169), from Italy *ca.* 1300, has only four stars on its rete, one each quadrant.[178]

In the case of the second layer of Arabic star names, scratched near their "Latin" equivalents, the hand is totally different from that of Masʿūd. It seems inconceivable anyway that he would have made these messy additions to his own astrolabe. Thus it seems reasonable to postulate a second Arabic hand.

These additional names are given in the Table. Several are difficult to see and not a few difficult to read. No equivalent name has been given for 9ABI (no. 19), doubtless because this was not a standard astrolabe-star and the Latin name seemed so strange; one name (no. 11), scratched around the hole at the base of the star-pointer, is illegible; and another (no. 18: *ṭ-r-w*) makes no sense.

p) The astronomical markings on the three original plates

The latitudes on the three plates that belong together (hereafter P1-P3) serve Jerusalem and Reims (see §3r) as lower and upper limits. The remaining latitudes span the range 40°-45°, bounded by Toledo in the

[175] *Idem*, *Sternnomenklatur der Araber*, p. 112, no. 290a.

[176] See n. 164 above.

[177] *Ibid.*, p. 86, no. 194a.

[178] King, "Medieval Italian Non-Standard Astrolabe", §B4.

south and Vienne (or maybe Lyon) in the north. These latitudes can act as a guide to the provenance of the instrument.[179] We may be confident that the astrolabe was made either in Central or Northern Spain or Southern France, favouring the former possibility. See further §3s.

The lightly-engraved initial horizons for 45° on the plates for latitudes $32^1/_2$° and 43° suggest that the maker started working on them and

[179] See n. 36 above. For comparison we note the latitudes on three medieval Catalan pieces (see further King, "Earliest European Astrolabe", pp. 372-376, and King & Maier, "Catalan Astrolabe", pp. 677 and 690-695) as well as the unique astrolabe with Judaeo-Arabic inscriptions (see *Khalili Collection Catalogue*, II, pp. 214-217, no. 124):

First, #3042 has astrolabic markings for latitudes 36°, 39°, 41;30°, 45° and 47;30°. Only the third latitude is associated with any locality, namely, "ROMA ET FRANCIA", which refers to Rome and Catalonia, the latter where the instrument appears to have been made. What the maker had in mind for the other latitudes we can only speculate, and it is difficult to know whether a Graeco-Roman tradition or the Islamic tradition is more relevant: 36° – [Rhodes / "Africa" / 4th climate]; 39° – [Sicily / Naples / boundary between 4th and 5th climates]; 45° – [Vienne / Po Valley / 4th climate]; 47;30° – uncertain, one possibility is Heraclea Pontica on the Black Sea. See further King, "Geography of Early Astrolabes", pp. 11-12.

Second, #162 has plates for latitudes 32;30°, 38;30°, 39;40°, 41° and 42°, with no place-names. These might serve Jerusalem, Cordova, Valencia, Barcelona/Rome (?), and Pamplona/Gerona (?). This piece was probably made in Valencia.

Third, #416 has plates for 31° – Damietta, 32° – Jerusalem, 33° – "Africa", *i.e.*, the Maghrib, 34° – Tripoli, 35° – Ceuta, 38° – Sicily, 39° – Valencia, 40° – Segovia, 41° – Barcelona, 42° – Pamplona, 43° – Macedonia, 44° – Genoa, 45° – Milan, 46° – no locality specified. This piece was made in Catalonia, therefore only Valencia and Barcelona come into consideration.

Fourth, #3915, the astrolabe with inscriptions in Judaeo-Arabic, has plates for: 29° – Sijilmasa, 30° – Cairo, 31° – Marrakesh, 32° – Jerusalem, 37° – Tunis, 37° (?) – Seville, and 38° – Cordova. This information is more of academic than practical interest because the markings on the plates do not correspond to these latitudes. It is not clear whether the instrument was made in al-Andalus or the Maghrib.

The dangers of trying to identify which locations astrolabe-makers had in mind when we know only the latitudes they used for their plates are well illustrated by the French quatrefoil astrolabe #546. Here the localities are mentioned and not a few are surprising: 32° – Jerusalem; 36° "Affrica" [= Tunisia]; 42° – Rome; 45° – Montpellier; 47° – "CATVR" (unidentified, perhaps Tours); 48° – Paris; 53° – no location specified. On the French quatrefoil astrolabe #3058 the remaining original plates serve: 37° – Carthage; 38° – Tunis; 41° – Armenia; 42° – Rome; 45° – Cremona; and 49° – Paris. There is a replacement plate for 52° – London and 53° – Lincoln.

changed his mind about which latitude he really wanted the plates to serve.[180]

There are occasional problems with the markings, namely:

$32^1/_2$°	circle for the winter solstice;
40°	azimuth circle at 10° to the left of the upper meridian; one azimuth circle extended too far towards zenith;
42°	circle for the winter solstice; uppermost altitude circle; altitude circle for 66°;
43°	uppermost altitude circle;
45°	circle for the equinoxes has been engraved double; uppermost altitude circle;
$49^1/_2$°	right-hand side of the prime vertical, that is, the azimuth circle passing through the east- and west-points.

These may be compared with the markings on P4 where a different maker has become unstuck – see §3u. In addition, however, on these three plates the construction of the azimuth curves is non-standard – see §3q.

On P1 and P2 there is a small hole at the intersection of the meridian with the circle for the winter solstice. This is not uncommon on medieval astrolabe plates.[181] On P3 the hole is at the right hand intersection of the horizontal diameter and the winter solstice circle for 43° and the left-hand intersection for $49^1/_2$°, almost as if the engraver made the hole, then went ahead with the rest of the markings forgetting about the hole. There is no such hole on P4.

[180] This calls to mind a North Italian astrolabe dated 1420 (#4523) on which all the plates are for latitude 45°, serving the Po Valley but also the middle of the 6th climate, even though they are labelled for a series of different latitudes. See further Stautz, "Astrolab aus 1420".

See *Nuremberg GNM 1992-93 Exhibition Catalogue*, II, pp. 589-592 (no. 1.77), especially fig. 1.77.3, for a horizon for *ca.* 49° on astrolabic markings for *ca.* 46;30° on a German instrument dated 1468 (#550).

[181] Documentation of this phenomenon would be difficult. The purpose of the holes is unclear.

q) *The construction of the azimuth circles on the three original plates*

On each of P1-P3 there are two rows of eight equi-spaced construction marks between the intersections of the circle for the equinoxes with (1) the meridian below the horizon and (2) either side of the horizontal diameter. The azimuth circles, when produced below the horizon, pass through these points. This indicates that the points were used for the construction of the azimuth circles (which also all pass through the zenith). The centre of the prime vertical, visible on the meridian below the horizon, is then determined, and the centres of the other azimuth circles, also visible, would have been determined as the points on the perpendicular to the meridian through this point that are equidistant from the zenith and the appropriate point on the construction lines. Such a procedure is not only approximate and not much simpler than the rather cumbersome standard method (as used by Mas'ūd on P4), it is also wrong. Although the azimuth circles are not noticeably differently placed with regard to the horizon, on either side of the meridian above (*i.e.*, to the south of) the zenith, they are wildly divergent from reality.

Now this procedure is unknown to the modern literature, and no medieval texts describing it are currently known either.[182] It is, however, clearly related to a procedure outlined in a 13th-century manuscript of an anonymous Spanish Latin treatise on the construction of the astrolabe.[183] No other medieval astrolabes are known to bear such construction marks, but since the procedure was hitherto unrecorded, no such markings have ever been sought on astrolabe plates.[184]

[182] Various procedures, all exact, are described in Berggren, "Construction of Azimuth Circles", and, most recently, Lorch, "Rudolf of Bruges on the Astrolabe", pp. 90-91. See also Michel, *Traité*, pp. 53-56, and Hartner, "Astrolabe", A, pp. 296-298.

[183] Edited in Millás Vallicrosa, *Traducciones orientales*, pp. 318-319 (I owe this reference to François Charette). On the problematic attribution assumed by Millás see Kunitzsch, "Astrolabe Treatise Ascribed to Messahalla", p. 49, especially n. 35. The procedure and this text should be investigated further.

[184] In the same way it was a surprise to find that the shadow squares on two 14th-century Northern French astrolabes (#198 and #202) were constructed by an approximate procedure. There the procedure is likewise incorrect and the divergence even more obvious. See further King, *Ciphers of the Monks*, pp. 416-417.

Furthermore, on each of these plates there is a set of points on what appears to be part of an altitude curve at about 30° below the horizon on the left-hand side of the meridian (most clearly visible on the plate for 43°). The purpose of these markings has not been established.[185]

r) The plates for Jerusalem and Reims

The inclusion of Jerusalem, common on medieval European astrolabes, may have been *pro forma*, imitating the presence of Mecca on Islamic astrolabes. If the maker was a Christian there may have been in his mind the eventuality that the instrument might be used by a pilgrim or by a crusader.[186] And if he was a Jew, even one converted to Christianity, a plate for Jerusalem would have been doubly appropriate. Such a plate is found on the Judaeo-Arabic astrolabe #3915, but not on the later Jewish astrolabes (#158, #159 and #3906) – see §3t. In addition we note that 32;30° for Jerusalem is not an Islamic value,[187] but it is found on the Catalan astrolabe #162.[188] One possible implication is that some Crusader took the trouble to measure the latitude of Jerusalem, although his value 32;30° is less accurate than the standard Islamic values 31;50° and 32°0 (the correct value is 31°47′). Another is that this was a compromise between two Islamic values, 32;0° and 33;0°.

[185] They are not related to the unusual circles for twilight that are found, for example, on the 14th-century Picard piece #202. On each of the plates of that piece we find an altitude circle below the horizon which is tangential to the equinoctial circle, and whilst the approximation to the conditions of dawn and nightfall is reasonable for the latitude of, say, Paris, for lower latitudes the error is considerable. See further King, *Ciphers of the Monks*, pp. 412-414 and 416.

[186] On the earliest European astrolabe we find Rome rather than Jerusalem, but not necessarily because Rome was important to the maker, but rather possibly because the instrument seems to bear traces of a *Roman* tradition of astrolabe-making. See n. 210 below.

[187] Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. 160-161.

[188] See n. 179 above and also King & Maier, "Catalan Astrolabe", p. 692.

The inclusion of a plate for 49;30°, too high for Paris,[189] is surprising but can be explained. Various values were used for Paris in the Middle Ages, and they all lie between 48° to 49°.[190] On the other hand Reims is given latitude at 49;20° in a 15th-century English geographical table (the correct value is 49°15′).[191] In earlier sources it is given a latitude far too low, but is identified as *sedes regis francorum*, "the seat of the king of the French",[192] and that is why it is featured here. More specifically, however, in 1234 Count Thibaud IV of Champagne had become king of Navarre, and in 1284 Countess Jeanne of Champagne and Navarre married Philippe le Bel, so that there were strong ties between Navarre and Reims.[193] This is, alas, not sufficient evidence to assume an origin for the astrolabe in Navarre, although Jewish craftsmen were active in such centres as Pamplona and Tudela. If the astrolabe was made there it might have ended up in the hands of the *mudéjar* Mas'ūd further south.

s) The other localities served by the original plates

It was usual for medieval astrolabe-makers to prepare plates for a span of latitudes on either side of the latitude of their own location.[194]

[189] In *Nancy 28.06.1998 Pamphlet* it is assumed this plate is for Paris, adducing #190, an astrolabic plate supposedly for latitude 49;30°, in support of this. However, the latitude engraved on that plate is 48;50° not 49;30°.

[190] North, *Horoscopes and History*, p. 194. Where we find 49°, as on the 14th-century French astrolabe #3058, and on the 15th-century French additions to the 14th-century Italian astrolabe #548, it is most probably rounded from 48;50°, or from another common value, 48;48°. The former is given by Jean Fusoris *ca.* 1400 in his treatise on the construction of the astrolabe – see Poulle, *Fusoris*, p. 100.

[191] *Ibid.*

[192] Reims, identified only as *sedes regis francorum*, is at 45;50° in two 12th-century sources, the *Toledan Tables* and the *Marseilles Tables* (Ptolemy had 45;30°) – see Kennedy & Kennedy, *Islamic Geographical Coordinates*, p. 285.

[193] See *Paris GP 1998 Exhibition Catalogue* on the fates and fortunes of Philippe and his sons.

[194] Andalusī astrolabes do not accord with this rule, not least because to the north lay regions inaccessible and undesirable to their Muslim makers. Thus, for example. #1099,

Occasionally they did later historians the favour of marking the name of that locality, but alas that is not the case here. The three plates serve latitudes:

$32^1/_2$	**42**
40	45
43	$49^1/_2$

In the light of these three plates alone the latitudes 42° and 43° could be considered the most reliable pointers to the provenance: in some medieval geographical tables both values are associated with Narbonne (and nowhere else),[195] but this city is too far north and not where one would expect to find an Arab engraver. But 42° might also have been intended for Barcelona (as on #416), although it is too high and linguistic considerations speak against a Catalan provenance for our piece. It could also have been intended for Saragossa, whose latitude was taken as 41;30° (as on #1099, actually made in Saragossa, #117, #118, *etc.*) or 42° (as on #110, #3650, #2572, *etc.*), or even 43;30° (as on #116). The composite European astrolabe #191 has 41° for Saragossa. In that city, as well as in Toledo (see below), there were Jewish metal-workers in the Middle Ages.[196] Burgos is another possibility for latitude 42°. A solitary 11th-century plate in an Andalusī astrolabe dated 638 H [= 1240/41] (#154) has 40° for Toledo and 42° for Burgos; no other Islamic astrolabes have markings for Burgos.[197] In a 15th-century Spanish gazetteer the latitude of Burgos is given as 43;4°.[198] Another possible choice for latitude 43° would be Pamplona, capital of Navarre, although on the medieval Catalan astrolabe #416 it is put at latitude 42°.[199]

made in Saragossa in the late 11th century, has 11 sets of markings for latitudes between those of Mecca and Saragossa, but nothing beyond.

[195] North, *Horoscopes and History*, p. 193.

[196] See n. 9 above.

[197] In *Chicago AP Catalogue*, I, pp. x-xi, the astrolabe itself is stated – presumably citing a one-line description from the 1920s – to be from Toledo.

[198] Cátedra & Samsó, *Astrología de Enrique de Villena*, p. 94.

[199] See n. 179 above.

Now the fourth plate is not original and it may be that an original fourth plate bore markings for, say, 38;30° (for Cordova, in Christian hands since 1236 and often featured on early European astrolabes, *e.g.* #162) and 44° (if only for the sake of completeness). This would fit nicely into the arithmetical organization of the latitudes on the plates, thus:

$32^1/_2$	42
[$38^1/_2$	44]
40	45
43	$49^1/_2$

In this case latitude 40° would come into consideration as a pointer to provenance, which would most likely be Toledo. This has the advantage that it was the main centre of Jewish activity in metalwork in the whole of Spain.[200] The parameter 40° was the only serious latitude for Toledo in Islamic geographical tables,[201] possibly rounded from the value 39;52° (accurate to the minute) found aleady on some 11th-century Andalusī astrolabes,[202] and in the 15th century the value 39;53° or 39;59° is given in a Christian Spanish source.[203] Another possibility for the original fourth plate would have been the latitudes 37;30° (for Seville, recaptured by the Christians in 1248) and 38;30° (for Cordova); this again would point to a slightly higher latitude for the provenance, say, 40° for Toledo. If the hypothetical original plate had borne markings for, say, 36° (Almeria) and 38;30° (Cordova), both standard on medieval Western Islamic astrolabes, Mas'ūd might have resisted the temptation to engrave a new plate.

[200] See nn. 9 and 196 above.

[201] See Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. 357-358;

[202] In King, "Geography of Early Astrolabes", pp. 16-17, I claimed that 39;52° was one of the values attributed in the 13th-century *Libros del saber de astronomia* to the Andalusī astronomer Ibn al-Zarqālluh in 1067. But, as my good friend and colleague Julio Samsó took pleasure in pointing out to me, this list of values was inserted by the 19th-century editor, who had taken it from the astrolabe #116! So we *still* do not known who derived this excellent value for Toledo.

[203] Millás Vallicrosa, "Astrología de Enrique de Villena", p. 416: "40 menos 7 min.", and Cátedra & Samsó, *Astrología de Enrique de Villena*, p. 94: "40 menos un minuto".

t) The Hebrew inscriptions on the three original plates

The latitudes of the six sides of the three original plates are scratched in Hebrew alphanumerical notation at the bottom rim of each side. They are expressed sexagesimally (in degrees and minutes) because in Greek, Arabic and Hebrew this kind of notation alone is used for sexagesimal numbers and fractions.[204]

The positioning of these scratches seems to indicate that they were added in the course of construction.[205] In other words, one of the persons involved in the construction was a Jew.

The number of astrolabes with original inscriptions in Hebrew characters is few indeed. The earliest one is that with inscriptions in Judaeo-Arabic (#3915), dating from *ca.* 1300. Then there are three astrolabes with inscriptions in Hebrew, clearly from the same milieu, probably Italian, possibly Bologna,[206] and apparently dating from *ca.* 1400: #158 (London), #159 (Chicago), #3906 (Paris, private collection). The back of another astrolabe #621 (Munich) may come from the same tradition. Finally, there are Hebrew additions to two 11th-century Andalusī astrolabes: #2572 (a replacement rete with Hebrew inscriptions), and #116 (additions to the solar and calendar scales as well as the plates for Toledo and Cordova); to an Italian astrolabe from *ca.* 1300: #4509 (Hebrew names of the signs and the months); and to a 14th-century

[204] On Hebrew alphanumerical notation see the references in n. 51 above. On sexagesimal notation see, for example, Berggren, *Episodes*, pp. 39-48.

[205] Several astrolabes have interpretations of or corrections to the latitudes indicated just below the inscriptions mentioning the latitudes – see, for example, King, "Astronomical Instruments between East and West", p. 153, fig. Vc. The custom of marking *batch numbers* near the pegs on plates was followed by Georg Hartmann in Nuremberg in the early 16th century – see, for example, *Nuremberg GNM 1992-93 Catalogue*, II, pp. 593, 594c and 596a.

[206] The only clue to provenance on the four astrolabes is that one of the plates on #159, albeit a poorly-made piece lacking the quality of the others, bears the name Bologna (and also Paris) in Hebrew – see *Chicago AP Catalogue*, I, pp. 58-60 (no. 7). The three pieces are discussed together in Goldstein, "Hebrew Astrolabe", but a more detailed comparative study would be worthwhile. On the dating see *ibid.*, pp. 156-157.

English astrolabe: #293 (owner's mark in Hebrew on the throne and Hebrew abbreviations for zodiacal signs and month-names on the back).

u) The fourth plate

P4 is slightly thicker than each of P1-P3 (see §2j and §2l). Although the markings "look" as if they are by the same maker, not least because the divisions are the same and the azimuth circles do not extend beyond altitude 78°, we note first that:

(1) P4 has no markings in Hebrew, such as are found on P1-3.
(2) P4 has no small hole at the intersection of the meridian with the circle for the winter solstice, such as are found on P1 and P2, and in a different position, on P3.

In addition there are various differences in the construction marks, notably:

(3) The maker of P4 marked a short incision at some of the points where the altitude circles cut the meridian; these marks are lacking on P1-3.
(4) On both sides of P4 the centres of the azimuth circles are clearly visible on a horizontal line below the horizon; on P1-3 there are traces of a different, approximate construction, although the centres of the azimuth circles are also present – see §3q.
(5) On P1-3 below the horizon there are short lines to mark the divisions on the circles corresponding to the equinoxes and solstices, as an aid in the construction of the curves for the seasonal hours; these are lacking on P4.
(6) On P4 there are several azimuth curves which are slightly too long or slightly too short at the horizon; this is not the case on P1-3.
(7) On P4 two of the hour-curves on the side for Mecca are duplicated; there are no such problems with any of the hour-curves on P1-3.

In general the markings on P4 are slightly less carefully executed than those on P1-3, but, as noted in §3u, the latter are not without occasional

problems. On P4 there are also problems with the curve for the *ẓuhr* on the side for Algiers, which has been duplicated along most of its length.

A metal analysis could provide definitive proof whether the fourth plate came from the same workshop as the other three. The visual evidence suggests that at least the raw plate did.

See §4e on the latitudes used by Mas'ūd for Mecca and Algiers.

v) The times of Muslim prayer on the plates for Algiers, Mecca and Jerusalem

Markings for the times of Muslim prayer[207] are standard on Andalusī and Maghribī astrolabe plates. The times of the prayers shortly after midday and mid-afternoon prayers (*ẓuhr* and *'aṣr*) are defined by shadow-lengths and they are marked by special curves amidst those for the seasonal hours. In order to draw them one needs only to know the times of the prayers at the equinoxes and solstices, mark these on the corresponding base-circles and construct the arc of a circle through the three points. The times of the night-time prayers are at nightfall and daybreak, defined when the sun has a certain angle of depression below the horizon, usually taken as 18° by Andalusī astronomers. The altitude circle for -18° can be drawn, but it is easier to mark the altitude circle for +18° in a special way and to use the point opposite to the sun on the ecliptic ring. In the case of the astrolabe under discussion, as on most Andalusī astrolabe plates, the latter procedure has been adopted.

On the plate for Algiers, there are thus two curves serving the daylight prayers and there are fish-bone markings on the altitude circle for 18° between the solstices. None of these markings is labelled.

On the plate that serves the latitude of Mecca, only the altitude circle for 18° is marked, and there are no curves for the daylight prayers. Furthermore it should be noted that not a single known European astrolabe has astronomical markings specifically stated to be for the

[207] For an overview see the article "Mīḳāt. ii" [= astronomical timekeeping and the regulation of the times of prayer] in EI_2, reprinted in King, *Studies*, C-V, also the article "S̲h̲afaḳ" [= twilight]. More details on the origins of the definitions of the times of prayer, and how they were applied in practice over the centuries, is in *idem*, *SATMI*.

latitude of Mecca, even though some such instruments have extensive ranges of latitudes from the equator to the northernmost inhabited regions.[208]

On the plate serving the latitude of Jerusalem the altitude circle for 18° has been marked in a similar way, but not necessarily by the same hand. There are no additional markings for Muslim prayer-times on any of the other original plates. If Mas'ūd was indeed active in Toledo or Saragossa one might have expected him to have added markings on the appropriate plate.

We have noted that there are no labels on any of these prayer-curves, even though it was standard practice in Andalusī and Maghribī astrolabe-making to label such curves. Are we here witness to yet another attempt to dissimulate and not to draw attention to Mas'ūd's religion? See further §4d.

w) The scales on the back

The presence of a calendar and solar scale on the back is precisely what we should expect on a medieval European astrolabe.[209] This tradition was adopted from earlier Western Islamic astrolabes, on which such scales appear already in the 10th century, if not before. And that earlier tradition seems to be inspired by a Roman tradition, if the evidence provided by the 10th-century Catalonian astrolabe (#3042) has been correctly interpreted.[210]

Yet there was also an Eastern Islamic tradition of such scales. First, the great scientist al-Bīrūnī (Central Asia, early 11th century) mentions an

[208] The 14th-century French (?) piece #2041 does have a plate for latitude 22°, but no localities are mentioned on any of the plates, which serve 10 latitudes between 22° and 48°.

[209] Thus, when there is no such scale on a medieval European astrolabe, we may suspect that we are dealing with a copy of an Islamic instrument: see King, "Medieval Italian Non-Standard Astrolabe", §B6, on #169.

[210] King, "Earliest European Astrolabe", pp. 384-385. The first paragraph on p. 384 should have been preceded by the words "Added in Proof".

astrolabe bearing the names of the Byzantine months.[211] And second, a few astrolabes from 12th- and 13th-century Syria, Egypt and the Yemen have such scales, either for the Syrian months (for example, #103, #140 and #4029) or for the Coptic months (for example, #106).[212]

Since the front of the astrolabe under discussion is to all intents and purposes European in execution if not in style, we may assume that the scales on the back were originally intended to be engraved with the appropriate Latin forms of the names of the zodiacal signs and months. Mas'ūd engraved the Western Islamic forms of the European month-names. These were used by the Arabs in al-Andalus in the 14th century alongside the Muslim months; often dates are given in both calendars.[213]

x) The dates of the equinoxes and solstices

The dates of the equinoxes and solstices, namely:

III $13^1/_3$ VI $15^3/_4$ IX $16^1/_2$ XII $14^1/_3$

correspond, at least for the equinoxes, to *ca.* 1200, but this should not be taken too seriously for the purpose of dating the astrolabe.[214] For comparison we note that:

a) the Catalan astrolabe #3042 of supposedly *ca.* 975 has the vernal equinox at III 15;

[211] On al-Bīrūnī see the article in *DSB*. For the quote see King, "Earliest European Astrolabe", p. 376, n. 39.

[212] See n. 129 above.

[213] For some examples see van Koningsveld, "Arabic Manuscripts from Christian Spain", A, pp. 85-87.

[214] This dating is based on a computer-generated table of dates of the equinoxes and solstices for each 100 years from 0 to 2000 prepared by Dr. Benno van Dalen, Frankfurt. In *Nancy 28.06.1998 Pamphlet* the vernal equinox is associated with the second quarter of the 14th century. On the problems associated with this kind of dating see the studies cited in n. 37 above.

b) an early Spanish or French astrolabe #161 (present location unknown) also has III 15;
c) an early medieval astrolabe of uncertain provenance #420 has III 14;
d) the Catalan astrolabe #162 of supposedly *ca.* 1300 has III 12;
e) the other Catalan astrolabe #416 of the same supposed date has III 11.5; and
f) the astrolabe of Petrus Raimundus dated Barcelona, 1375 has III 12.

Only the last of these instruments is actually dated, and the dates assumed for the others may be in error by as much as ±50 years.

y) The use of silver

Silver is used for the buttons at the base of star-pointers as well as the handles on the retes on several 11th-century Andalusī astrolabes, as well as on the unique astrolabe with Judaeo-Arabic inscriptions. In the holes on the star-pointers here there is no trace of silver, thus the holes are purely decorative.

Only one medieval European astrolabe has any inlaid silver or any kind of cartouches for inscriptions. This is #213, a piece of uncertain date and provenance: on the back of this, illustrations of the zodiacal signs are inlaid in silver. Unfortunately, however, the location of this piece is unknown and no photos of the back are known to exist.[215] Also, no known astrolabe from the Islamic West has inlaid silver cartouches, or indeed any kind of cartouches, for the inscriptions,[216] other than #4182, made in Fez in 719 H [= 1319/20], where the signature on the back is enframed in a barbed quatrefoil: see Figs. 12b-c. Another piece, #4217, made in Granada in 886 H [= 1481/82], has silver inlay, this in decorative single-leaf-forms

[215] An illustration of the front is in Culver, "Early European Instruments", p. 34. See also Gunther, *Astrolabes*, II, pp. 361-362 (no. 213); Gunther's dating to the end of the 16th century is much too late.

[216] Cartouches are common on later Islamic astrolabes from Safavid Iran (17th and early-18th century), particularly for arguments on scales and place-names in geographical gazetteers.

on the front of the throne (in addition to the silver knobs on the rete and silver buttons on the star-pointers). A substantial number of surviving astrolabes from Ayyubid and Mamluk Egypt and more especially Syria are inlaid with silver, in fact, some eight out of a total of thirteen known pieces from Egypt or Syria during the period 1150-1300.[217] A spectacular example is #137, an astrolabe by al-Sahl al-Nīsābūrī, made in Syria between 1180 and 1280. Here the circus-figures decorating the rete are inlaid with silver, and the star-names are engraved on the silver. Two more are the splendid instruments of ʻAbd al-Karīm al-Miṣrī, made *ca.* 1230 probably in Damascus, the first complete (#104), the latter with replacement rete (#103); on these the thrones and some of the inscriptions are inlaid in silver. Finally, one Mamluk Egyptian astrolabe with inscriptions in Arabic and Coptic (#4036) has all the inscriptions on the rete, the mater, the back and the plates inlaid in silver.[218] There are numerous examples of Mamluk metalwork which reflect the skill and enthusiasm of Egyptian and Syrian craftsmen in inlaying silver and gold in brass: one of the most magnificent is the basin known as the "Baptistère de Saint Louis" in the Musée du Louvre, from the second half of the 13th century.[219] If we were to suppose that Masʻūd was an Egyptian or Syrian, then it could be possible either that he commissioned the silver cartouches and showed his predecessor how to inlay them, or that he actually collaborated with that person in preparing them for his own use. On the other hand, as we shall see, it seems more likely that the silver inlays derive from an Andalusī tradition, not least by virtue of their shape.

The question *why* anyone would want to highlight with silver inlay the names of the signs of the zodiac and the solar months is another matter.

[217] An astrolabe with silver inlay is mentioned as belonging to a barber in one of the *1001 Nights*. Here the account is surely inspired by a Syro-Egyptian astrolabe (the entire corpus of tales is Syro-Egyptian in origin, although the location of the alleged events is Baghdad). The text is extremely corrupt yet can be partially restored to reveal the astrological implications of an observation that was reportedly made. For two studies of this text see Vernet, "La conjunción del barbero", and Maddison, "Barber's Astrolabe".

[218] See n. 257 below.

[219] See Mayer, *Islamic Metalworkers*, pp. 74-75, and, most recently, Behrens-Abouseif, "Baptistère de Saint Louis".

Perhaps we are witness to some interest in the astrological significance of the zodiacal signs, which is richly reflected in a subset of inlaid Islamic brass-ware.[220] This having been said, it should be noted that on the richly-decorated astrolabes of ʿAbd al-Karīm al-Miṣrī mentioned above, the names of the signs and months are not inlaid. Furthermore only rarely do medieval European astrolabes bear astrological information on the scales on the back.[221] And alas #231, the only European astrolabe with artistic representations of the zodiacal signs in inlaid silver on the back is unavailable to us.

It is easier to understand, for example, why the curves for the times of Muslim prayer (and no other features) are inlaid in silver on the plates of #109, made by the Yemeni Sultan al-Ashraf in 690 H [= 1291]:[222] the times of prayer are the most important times during the Islamic day.[223] Likewise the curves displaying the altitude of the *qibla* or local direction of Mecca at Herat and Samarqand (and no other features) are inlaid in silver on the plates of #3595, an astrolabe made in 830 H [= 1426/27] for the astronomer-prince Ulugh Beg.[224] The Prince was wont to oscillate between these two main cities of his realm, and in whichever he was, he could use his astrolabe to determine the sacred direction.[225]

[220] See most recently *New York MMA 1997 Exhibition Catalogue*, and another example in *Paris IMA 1995 Exhibition Catalogue*, p. 457 (no. 370).

[221] See Glasemann, "Zwei mittelalterliche französische Astrolabien", pp. 221-222 and 230, dealing with the astrological properties of the lunar mansions. This article explains the markings on #549, an unsigned astrolabe of the Vienna school dated 1457 – see *Nuremberg GNM 1992-93 Exhibition Catalogue*, II, p. 583.

[222] See King, "Astrolabe of a Yemeni Sultan", pp. 104-105 and pls. 4-7, and *idem*, "Strumentazione", p. 163.

[223] See n. 207 above.

[224] See King, "Strumentazione", p. 165, and *idem*, *Mecca-Centred World-Maps*, pp. 106-108. See also n. 258 below.

[225] See article "Kibla. ii. Astronomical aspects" in *EI*$_2$, reprinted in King, *Studies*, C-IX.

z) *The shape of the cartouches*

The cartouches are essentially rectangular (albeit with the longer sides as circular arcs to fit within the boundaries of the scales) with simple half-quatrefoil decoration at each end:

Cartouches of this kind are not uncommon on late Islamic metalwork from Syria eastwards,[226] as well as in *Qur'ān* illumination from 15th- and 16th-

[226] Some examples:

- A bronze jug made by Shīr 'Alī ibn Muḥammad Dimashqī in 872 H [= 1467/68] – see Mayer, *Islamic Metalworkers*, p. 83 and pl. XIV.
- A steel sabre from Ottoman Turkey, datable *ca.* 1540 – see Welch, *Muslim Calligraphy*, pp. 94-95 (no. 30).
- Two undated signed Eastern Islamic copper vessels – see Mayer, *Islamic Metalworkers*, pp. 47 and 80, pls. VII and XII.
- A jewelled silver *Qur'ān* cover from Kasimov in Central Russia dated 1002 H [= 1593/94] – see *Kuwait Hermitage 1990 Exhibition Catalogue*, pp. 35 and 128-129 (no. 109).
- Some late-16th-century Iranian bath-pails, hawking drums, torch-stands and pouring vessels – see Melikian-Chirvani, *Iranian Metalwork*, pp. 306-311, *Geneva MAH 1985 Exhibition Catalogue*, p. 287, and *Copenhagen DS Catalogue*, p. 351.
- A copper wine-bowl from early-17th-century Isfahan by an Armenian craftsman – see Welch, *Muslim Calligraphy*, pp. 142-143 (no. 57).
- An "Elijah chair" (date uncertain) for circumcision ceremonies, in a synagogue in Qaṣr Shirīn in Iranian Kurdistan – see *Sepharad*, p. 76.

Most Iranian cartouches are pointed at the ends, as can be seen from a perusal of Melikian-Chirvani's splendid book, *Iranian Metalwork*. See also n. 120 above on a terracotta font from 14th- or 15th-century Muslim Spain with oblong cartouches, also with pointed extremities.

century Turkey and Iran,[227] but they are also found on various Naṣrid and *mudéjar* objects.[228] Indeed, essentially rectangular cartouches are a rather prominent feature of Naṣrid and *mudéjar* decorative art.[229]

The reader should be aware that we are dealing with an extremely simple design, when viewed in the light of the almost unlimited sophistication and variety of Andalusī decorative art.[230] However, one should be careful in assigning a particular design of this simplicity to any regional school. As a warning one might cite the presence of cartouches precisely like those on this astrolabe, with a quatrefoil attached at the extremity, in the decoration of the Mosque of Ibn Ṭūlūn in Cairo, built during the period 876-79.[231]

[227] For two examples see Lings, *Quranic Calligraphy and Illumination*, pls. 88 (15th century Turkey), and 90 (16th-century Iran).

[228] Notably, five pieces with cartouches of this kind, sometimes separated by quatrefoils:

- A silk pillow cover of Sancho IV, late 13th century – see *Granada-New York 1992 Exhibition Catalogue*, p. 112, fig. 8.
- Fragments of a silk textile from Naṣrid Granada – see *Ars Hispaniae*, IV, p. 199, fig. 214.
- A glazed and painted terracotta tile designed as a textile, from Granada, datable *ca.* 1410 – see *Ars Hispaniae*, IV, p. 185, fig. 191, and more especially *Granada-New York 1992 Exhibition Catalogue*, pp. 360-361 (no. 113).
- Some *mudéjar* plaster decoration on the Alcázar in Seville, 1362 – see *Ars Hispaniae*, IV, p. 371, figs. 426-427.
- Some *mudéjar* decoration on the interior walls of the Iglesia de Santa Justa y Rufina in Maluenda (Zaragoza) – see *ibid.*, IV, p. 274, fig. 297.

See also the more developed red oblong cartouches on a silk textile fragment from the 14th century featured in *Granada-New York 1992 Exhibition Catalogue*, p. 335 (no. 97).

[229] A good example is the richly-decorated Naṣrid sword and scabbard in the Bibliothèque Nationale de France, datable to the late 15th century. See *ibid.*, pp. 284-286 (no. 61), although the five oblong cartouches with ends shaped < and > are actually on the side other than the one illustrated there, and they are better seen in *Paris BN Catalogue*, no. 6: "epée de Boabdil".

[230] See n. 139 above.

[231] Pavón Maldonado, *El arte hispanomusulman*, p. 114 and 117, design no. 90.

As noted already in §2e and §2p, the sides of the cartouches coincide with the corresponding sections of the circles defining the solar and calendrical scales. The marks of hammering on the inside of the mater confirm that the cartouches did not cover any original inscriptions. And they correspond to medieval techniques of preparing the surface to enable the brass to better receive the molten silver.[232]

&) The decoration around the names of the zodiacal signs in the outer cartouches

Above the names of the zodiacal signs on the back various Arabic letters and vowel-signs have been inserted. One might have expected some symbols denoting, say, the astrological lords of the various signs,[233] but the presence of these markings can partly be explained. We repeat the data, reminding the reader that ∅ denotes a *sukūn* or zero-vowel sign, * denotes a *shadda*, the sign denoting a doubled consonant, and ' represents the weak guttural *hamza*. (The last may be a vaguely degenerate floral design, like a barbed fish-hook.[234]) Furthermore the vowels *a*, *i* and *u* are written in the inscriptions as *ā* (= *alif*), *y* (= *yā'*), and *w* (= *wāw*).

al-ḥamal: ∅ ∅ *u*	*al-thawr: u a* or ∅ (squashed)
al-jawzā: ∅ (*altered*)	*al-saraṭān*: no marks
al-asad: ∅ *z* (= *zāy*) *d* (= *dāl*)	*al-sunbula*: ' *a i*
al-mīzān: *ḥ (= ḥā')* or *j* (= *jīm*) ∅	*al-'aqrab*: ∅ ∅
al-qaws: ∅ *a*	*al-jady*: *a*
al-dalw: *a* *	*al-ḥūt*: ' *a*

Thus by *al-ḥ-m-l* for Aries we find what could be taken as one or two *sukūn*s (zero vowel signs,∅) and a *ḍamma* (*u*-vowel). It is doubtful whether the engraver thought these would help the pronunciation. Correctly the word would be written in full *al∅-ḥamalu*, so that the word does have one *sukūn* and one *ḍamma* (this latter would normally be

[232] On these see Ward, *Islamic Metalwork*, p. 35-37, with illustrations.

[233] See Hartner, "Astrolabe", B, pp. 2547-2548 (pp. 304-305 of the reprint).

[234] Some examples are shown in *Granada-New York 1992 Exhibition Catalogue*, p. 337, on a late-14th-century Naṣrid pluvial.

suppressed in pause, as in an inscription), but not where the engraver put them. This kind of interpretation is confirmed by the *alif* (for an *a*-vowel) and a *shadda* (for a doubled consonant) after *al-dalw* for Aquarius. Correctly the word would be written *al-d***alw* in pause, pronounced *ad-dalw*, so that a *shadda* and an *a*-vowel are appropriate, again if not where he put them. Similar arguments could be made for the two *sukūn*s on *al-'aqrab* (from *al∅-'aq∅rab*), the *sukūn* and the *a*-vowel on *al-qaws* (from *al∅-qaw∅s*), and the *a*-vowel on *al-jady*. But this explanation does not hold for all of the signs, and it seems that Mas'ūd has simply used some of the various symbols as decoration. One implication of the above correspondences is that Mas'ūd copied these from some heavily vowelled original (see below) and used the vowels somewhat indiscriminately. In addition he also used criss-cross designs and simple flourishes to fill the remaining void spaces (see §3aa).

The *d* (= *dāl*) above the final letter of *al-asad* is an acceptable Arabic usage.[235] But the *z* (= *zāy*) above the *s* (= *sīn*) in *al-asad* was perhaps intended to show that the word was to be pronounced *al-azad* or *al-açad*. (Note the problems that non-Arabs have with the single *sīn*, so that, for example, the Arabic Ḥasan becomes Hassan and the Syrian al-Asad becomes El-Assad.) Early European attempts to render *qalb al-asad*, "the heart of Leo", included: *Calbalazeda*, *Galbalaceda*, *Calbalaceda*, *Calbalaze*, *Calbalazed* and *Kalb eleced*;[236] some of these surely reflect Spanish usage. More difficult to account for is the *ḥ* (= *ḥā'*) or *j* (= *jīm*) above the *z* (= *zāy*) in *al-mīzān*. The letter has no dot so could be read as *ḥ*, but it is given in the initial form, which is usually used, with or without a dot, for *j* in the *abjad* notation.[237] The *j* seems more probable, but a linguistic explanation of its presence is not apparent.

An alternative possibility, namely, that we might find here some coded message or magic formula, seems unlikely.[238] All that we have in the way

[235] See n. 124 above.

[236] Kunitzsch, *Arabische Sternnamen*, p. 76 (no. 30).

[237] Irani, "Arabic Numeral Forms", pp. 5-6 (pp. 714-715 of the reprint).

[238] On Arabic letter-magic and cryptography and see the articles "Ḥurūf, 'Ilm al-" and "Mu'ammā" in EI_2. The standard work on Islamic magic is Fahd, *Divination arabe*, to

of letters are ' (*hamza*), *zāy*, *dāl* and *jīm*, and even when combined with any set of vowels, or interpreted as a set,[239] even with a mystical interpretation,[240] or read as numbers (1, 7, 4 and 3),[241] these do not seem to have any connection with codes or letter-magic or numerology.[242]

9) *The names of the months and the decoration of the inner cartouches*

In the month-names, vowels that could theoretically stand for *a*, *i* or *u* or even a zero vowel are represented by *v* in the following rendering:

> *yvnāyvr* – *fvbrā[y]vr* (with one dot on the *y* instead of two) – *mārvs* – *vbrīl* – *māyū* – *yūnvyu* (the *-h* ending indicates a short *-u* or *-uh*) – *yūlvyu* (as for the previous month) – *vgh̲vsh̲t* – *sh̲vtvnbvr* – *vktūbvr* – *nūvnbvr* – *dvjvnbvr*

These are most probably intended as:[243]

which must now be added the splendid contribution of Emilie Savage-Smith to *Khalili Collection Catalogue*.

[239] If one had a set of the seven letters *jīm*, *zāy*, *kāf*, *ṣād*, *qāf*, *th̲ā'*, and *gh̲ayn*, one might be dealing with the Maghribī variant of the letters corresponding to the element water (*EI*$_2$, III, p. 595b, also Schimmel, *Islamic Calligraphy*, pp. 92-93), and could come to the not unrealistic conclusion that Mas'ūd intended to flee Spain by boat.

[240] Thus in 9th- and 10th-century Ismā'īlī mysticism, *alif* stands for the Divine Order, *jīm* for the Soul, *dāl* for Nature, *zāy* for the Heavenly Spheres, *etc.*: see Schimmel, *Islamic Calligraphy*, p. 93.

[241] Ignoring the *hamza*(s), we note that the date 743 H, which corresponds to a year in the mid-14th century, close to the time when this astrolabe was made, would be written with the letters for 700, 40 and 3, not 7, 4 and 3.

[242] On the 14th-century Syrian box mentioned in n. 273 below there is an inscription which defied interpretation by its publisher but which simply reads *budūḥ*, a well-attested talisman on which see the article "Budūḥ" in *EI*$_2$, Supplement.

[243] The vowelling is not secure. See, for example, Corriente, *Dictionary of Andalusi Arabic*, p. 174, where for December we find *dujunbur*, *dujunbir*, *dujanbir*, and *dujunbar*, some, if not all of which, result from the "feel " of the editors of the sources used by Corriente.

*yanāyir – fabrāyir – mārs – abrīl – **māyū** – yūnyu –*
yūlyu – aghusht – shutanbar – uktūbar – nuwanbar – dujanbar

The form *māyū* is unusual; usually in Andalusī sources, both texts and astrolabes, we find *māyu(h)*.[244] It seems that Spanish (or Portuguese, but not Catalan) influence is to be seen here.[245]

There are various mainly redundant but nevertheless correctly-placed *sukūn*s on these names. Of particular interest are the various *shadda*s (*), namely, on the *s* (= *sīn*) of *m'rs*, the *t* (= *tā'*) of *shtnbr*, the *k* (= *kāf*) of *'ktūbr*, and the *w* of *nwnbr*. It was a custom in Spanish Arabic to represent various European letters by the closest Arabic letter with a *shadda* attached.[246] Thus, for example, *č* was written as *j**, *ñ* by *n**, and *p* by *b** or *f**. It may be that the *shadda*s used here were intended to denote that the month-names should be pronounced ***mārss*** (why is not at all clear), ***shattanbar*** (< *shaptanbar*? although *pt* → *t* is attested in Spanish Latin[247]), and *nuvambar*. The *shadda* in *'k*tūbr* makes less sense, unless – and this seems *most* unlikely – it is misplaced and it is supposed to denote that the initial *alif* be pronounced as a short *o*.

As with the decoration of the outer cartouches, it may be that the signs were inspired by similar markings on an earlier Andalusī astrolabe, such as one of the pieces of Muḥammad ibn al-Ṣaffār. Now it so happens that two astrolabes made in Toledo by the same maker, Muḥammad ibn al-Ṣaffār, the first #3650, dated 417 H [= 1026/27] and the second #116 three years later,[248] present some of the very features that might have inspired Mas'ūd. The engraving on these pieces is distinctive and loaded

[244] *Ibid.*, p. 492, and Maier, "Romanische Monatsnamen", B, p. 256.

[245] Merlo, *Nomi romanzi dei mesi*, p. 129.

[246] Article "al-Andalus. x: Spanish Arabic" in *EI*$_2$, by G. S. Colin, especially p. 502a, and Colin, "Charte hispano-arabe", p. 377, n. 2.

[247] Castro, *Glosarios latino-españoles*, p. xliii.

[248] See n. 22 above. Mayer, *Islamic Astrolabists*, pl. II, shows the back, unencumbered by an alidade.

Fig. 14 The back of the astrolabe made in Cordova in 1029/30 by Muḥammad ibn al-Ṣaffār (#116). The Arabic engraving on the solar and calendar scales is complete with *sukūns* and vowels, and the Hebrew names of the signs and the months have been added to the Arabic ones. [Photo courtesy of the Museum of the History of Science, Oxford.

with mainly redundant *sukūns* and occasional vowels – see Fig. 14.[249] At least the first of these pieces was probably still in Toledo in the 14th century, as attested by the Hebrew name for Toledo on the appropriate plate (and also Cordova on another). One has perhaps to imagine another piece by the same maker, in the same distinctive and perverse Andalusī

[249] See already Maier, "Romanische Monatsnamen", B, p. 60, where it is noted that the *sukūns* are "teilweise redundant verwendet", that is, "partly used redundantly".

Kufic, extremely difficult to read,[250] on which there were also a few vowel signs as well.

aa) The endless knots on the cartouches

The criss-cross patterns like frames for a "noughts and crosses" game on the silver cartouches, and also near the end of the inscription on the shackle, are incomplete renderings of endless knots.[251] Three complete forms are found in the cartouches for *al-ḥamal* (Aries) and *al-jady* (Capricorn), and *dujanbar* (December) – see Fig. 8b. These endless knots, admittedly here sometimes fudged at the ends, were used as incidental decoration in Islamic art,[252] especially in Hispano-Mauresque art, most

[250] Thus Woepcke misread the name of the maker as "ibn al-Saal" (that is, ibn al-Ṣāl), an error repeated in Goldstein & Saliba, "Hispano-Arabic-Jewish Astrolabe", p. 19, n. 2. On #116 the name certainly looks like al-Ṣāl, but the medial *f* (= *fā'*) has been engraved like a *sukūn* above the horizontal line between the *ṣ* (= *ṣād*) and the long *a* (= *alif*). On #3650 the name al-Ṣaffār is clear. See also King, *Studies*, B-XV, p. 360, n. 10, on the problems of reading the name al-Ṣaffār in Andalusī Kufic on a marble sundial from *ca.* 1000.

[251] The term "endless" is to be somewhat loosely interpreted, and I use it to include interwoven endless loops or superposed folded strands.

[252] Such designs are known from Iranian, and also Syrian and Egyptian, decorative art. Some examples:

- an inkwell in brass with silver inlay, 12th century – *Kuwait 1990 Hermitage Exhibition Catalogue*, pp. 54-55 (no. 29);
- a bronze vase inlaid with silver, 12th- or early-13th-century Khurasan – Welch, *Muslim Calligraphy*, pp. 110-111 (no. 39);
- four mortars, Khurasan, between late 12th and 14th century – *London NG Catalogue*, II, pp. 312-313 (nos. 194-196) and 316-317 (nos. 199-201).

For endless knots in the decoration of a Hebrew manuscript from Toledo, *ca.* 1300, see Sed-Rajna, "Ateliers de manuscrits hébreux", fig. 3 on p. 348. For examples of endless knots tied into Arabic and Hebrew script see, for example, Lanci, *Simboliche arabiche*, III, pls. XXIX, XLIII, LVII, LIX and LI (Arabic, the last with the name of Allāh developed into a knot) and XLIV (Hebrew).

notably in Aragon.[253] They are also apparently known from Islamic magic.[254] We find similar but more complex knots, for example, on a 13th-century silk fragment now in the Instituto de Valencia de Don Juan in Madrid (Fig. 15),[255] and in an illustration of Islamic sacred geography – the world divided into sectors centred on the Kaʿba – in a 16th-century Tunisian navigational atlas preserved in the Bibliothèque nationale de France (Fig. 16).[256] As decoration on an astrolabe only two examples of

[253] In addition to the two Western Islamic sources mentioned below (nn. 255-256), see other examples in Pavón Maldonado, *El arte hispanomusulman*, pp. 62-63 and 96 (general), and pp. 94, 100, 102, 106, 107, 109 and 384. In particular we note:

- a design similar to the ones on the astrolabe in the Claustro de San Juan de Castrojeriz near Burgos (*ibid.*, p. 94);

and various "endless" knots from *mudéjar* architecture in Aragon, namely:

- one from the Aljafería in Saragossa (*ibid.*, p. fig. 104, no. 18);
- two from the Catheral of Teruel (*ibid.*, pl. 12 opposite p. 384).

More complicated patterns are to be found, for example, in:

- two 12th-century Almoravid *Qur'ān*s dated – *Granada-New York 1992 Exhibition Catalogue*, pp. 304-306 (nos. 75-76);
- a brass basin inlaid with gold and silver, dated 1252/53, Syria (?) – *Washington FGA 1986 Exhibition Catalogue*, p. 19, fig. 9; and
- a brass pierced globe inlaid with silver and black, Syria or Egypt, mid 14th century – *ibid.*, pp. 171-172 (no. 23).

Yet more complicated patterns of all are to be found on European work inspired by Hispano-Mauresque art, for example:

- a majolica plate made in Siena *ca.* 1525 – *Berlin MGB 1989 Exhibition Catalogue*, pp. 613-614 (no. 4/121); and
- a bronze plate with inlaid silver made in Venice *ca.* 1545 – see *ibid.*, pp. 203 and 603-604 (no. 4/100).

[254] Yet they are not mentioned, for example, in Kriss & Kriss-Heinrich, *Volksglaube im Islam*.

[255] See *Granada-New York 1992 Exhibition Catalogue*, p. 111, fig. 7 (also n. 277 below).

[256] On Islamic sacred geography see my *Enc. Islam* article "Makka. iv. As centre of the world" (repr. in King, *Studies*, C-X), especially fig. 7. On the navigational atlas of

endless knots come to mind, namely: (1) on the rete of an astrolabe with Arabic inscriptions but numbers in Coptic (#4036) made in Cairo in 681 H [= 1282/83],[257] and (2) on the rete of the astrolabe (#3595) made for the Ulugh Beg by the leading astrolabist of Samarqand in 830 H [= 1426/-27].[258] The inspiration for the Andalusī tradition was most probably the highly elaborate knots in 10th and 11th-century Visigothic manuscript illumination.[259]

Fig. 15 Endless knots on a 13th-century silk fragment from the Kingdom of Granada. Note also the use of ornamental *naskhī* script and the superfluous *sukūns* at the beginning and end of the inscription *al-baraka li-llāh*, "Blessing is from God". [Courtesy of the Instituto de Valencia de Don Juan, Madrid, inv. no. 2093.]

Aḥmad al-Sharafī al-Ṣafāqusī see Nallino, "Mappamondo di ash-Sharafī", and a forthcoming study by Mónica Herrera Casais (Frankfurt and La Laguna).

[257] Unpublished; an illustration of the rete is in Nasr, *Islamic Science*, pl. 73 on p. 120. See also n. 218 above. The knot is not independent; indeed, it forms part of a larger pattern.

[258] See n. 224 above. For illustrations of the rete see already *Copenhagen DS Catalogue*, p. 214, and King, "Strumentazione", pp. 161. The knot is independent, although attached to other decorative components of the rete.

[259] See, for example, *Madrid BN MSS Catalogue*, pl. VIII opposite p. 204, and *Madrid RAH MSS Catalogue*, pp. 91, 119 and 175.
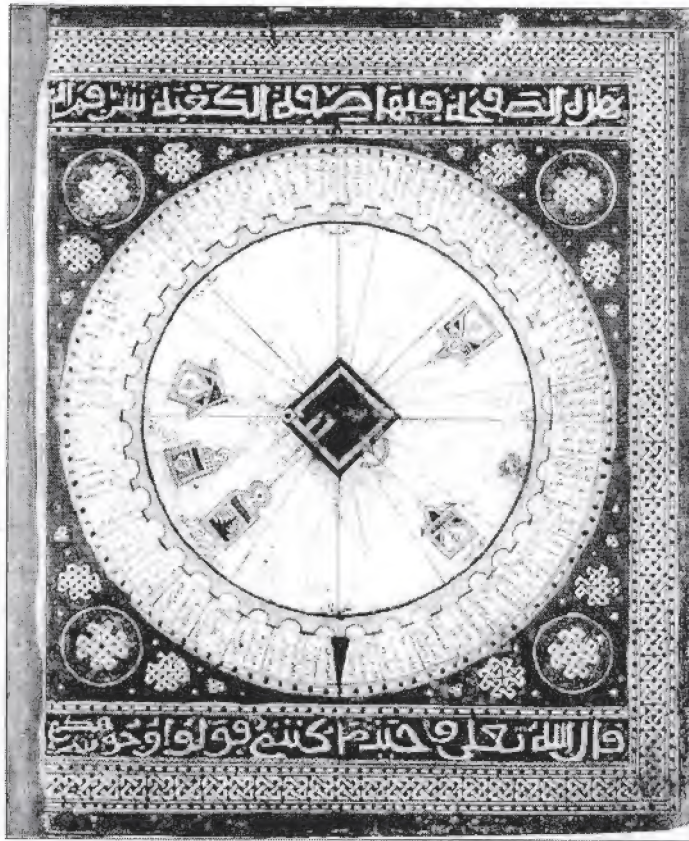
Fig. 16 Decoration with endless knots on a diagram of sacred geogrraphy in a 16th-century Tunisian atlas. [From MS Paris BNF ar. 2278, courtesy of the Bibliothèque Nationale de France.]

bb) The Spanish Arabic inscriptions reviewed

Mas'ūd has left us a unique document attesting to his vernacular Arabic. The star-names *dabrān* < *dabarān*, *g͟humayṣa* < *g͟humayṣā'* and *ṭāyir* < *ṭā'ir*; the month-name *māyū*; and the place-name *al-Jazāyir*. Possibly the *sukūn* on the *ṣ* (= *ṣād*) in *ṣāḥibuhu* at the beginning of his inscription on the boss of the shackle is intended to be on the *ḥ* (= *ḥā'*), so the word

would be pronounced *ṣāḥbuh(u)*. The *shadda*s (*) on various Arabic letters in the month-names appear to be purely decorative.

cc) One of the earliest surviving screws?

The only other known medieval astrolabe with a screw attachment is the 14th-century Picard piece #202.[260] In both cases the screws are hand-worked and appear to be original. If this is the case, then we are dealing with some of the earliest European examples of screws.[261] But it is easier to account for the male screw than for the thread inside the female cylindrical bolt. Here again metal analysis might be useful to investigate further whether these paraphernalia are original.

4 Concluding remarks

a) Who was the Jew who scratched the latitudes on the plates?

It may be that he was an assistant to the person who made the Latin engravings, a skilled craftsman, but nothing more. We cannot know to what extent he was involved in the construction, most of which, for lack of evidence to the contrary, we attribute to the person who made the Latin engravings. We cannot exclude the possiblity that the "European" mentioned below was not identical with the Jew who scratched the latitudes on the plates, perhaps even a converted Jew, which would mean that a single individual engraved both the Hebrew numbers and the "Latin" inscriptions. In any case, the Jew appears to have been active prior to the pogroms and mass conversions in 1391, which heralded the collapse of the Jewish community in Spain.[262] The association of this Jew

[260] King, *Ciphers of the Monks*, p. 419 and Fig. L.9.

[261] Two general histories of the screw are Treue, *Kulturgeschichte der Schraube*, and *Würth & Konstanz 1995 Exhibition Catalogue*. The screw was known in Antiquity, and on the development of the screw in Europe there is the chapter by A. P. Usher entitled "The screw and its development", in Singer *et al.*, eds., *History of Technology*, III, pp. 334-339.

[262] Scheindlin, "Jews in Muslim Spain", pp. 198-199.

with Toledo is strengthened by the fact that this was the major centre of metal-working in Spain in which Jewish craftsmen were involved.[263]

b) Who was the person behind the Latin engraving?

He was a local artisan, local to either Toledo or Saragossa, and was probably a Christian. He was a competent astrolabe-maker and engraver, and he adhered to a local tradition of using the old-fashioned inverted forms of '2' and inverted bar fractions. He favoured a distinctive scholastic orthography for the Latin script: the '9' for a hard C. Can this have been his own convention? Certainly we do not find it elsewhere. Yet he was not that well-versed in Latin or the manuscript tradition of star-names that he did not make mincemeat of some of the star-names on the rete.

On the other hand, he may have been a Jew or a Jew converted to Chistianity, in which case he was probably identical with the Jew who scratched the latitudes on the plates (see above). His ancestors would have witnessed the Muslim domination come and go.

Whoever he was, he was very familiar with the design of Andalusī astrolabes, and copied outright an Andalusī design for his rete and an Andalusī design for his throne. But he was also influenced by the new tendency amongst European astrolabe-makers to include plates for latitudes in Northern Spain and in France up to as far north as Paris, and just beyond to Reims.[264] He favoured a mid-13th-century Toledan tradition of astrolabe stars, although it is a complete mystery how he could have produced a set of star-names that were so different from those used in that tradition. Also, he used a curious, inexact (and previously-

[263] See n. 9 above.

[264] We can distinguish various earlier tendencies amongst European instrument-makers: first, the tradition of marking plates for the climates of Antiquity (as on #161 and #166, with relics on #169 (second climate only); see also #4024, a 10th-century Andalusī astrolabe with plates for the climates); second, the tradition of #3042, also left over from Antiquity (see n. 179); and third, the tradition of marking plates for a series of latitudes and an over-enthusiastic association of these with localities such as Africa and Macedonia (see again n. 179 on #416).

undocumented) Andalusī procedure for marking azimuth curves on astrolabe plates.

c) Why was the astrolabe not completed as planned?

For some reason, the astrolabe was not completed by the one or two persons mentioned above. All that remained to be done was to engrave the names of the zodiacal signs and the months on the scales of the back, which had already been inlaid with silver cartouches. The rete and four original plates had been completed, and the arguments had been engraved on all of the scales on the back, as well as the labels on the shadow-squares. Then something happened.

One possibility is that the maker(s) died. A prime cause of premature death in the mid-14th century was the Black Death.[265] The plague hit Saragossa in the year 1348 and four-fifths of the Jewish population were wiped out.[266] But no end of other hypotheses could be formulated.

d) Who was Mas'ūd?

Mas'ūd is a Muslim Arab name. (It is also a Christian Arab name, but it has no Hebrew equivalent.) Neither instrument-maker nor metal-worker with this name is known in the secondary literature.[267] Mas'ūd was a competent astrolabist in touch with the medieval Islamic astronomical-geographical tradition, because the fourth plate is executed with

[265] See n. 11 above.

[266] Article "Saragossa" in *EJ*, especially col. 861.

[267] This is essentially limited to Mayer, *Islamic Astrolabists*, and *idem*, *Islamic Metalworkers*.

The Mas'ūd al-Dahhān who translated a history of the Jews by Judah ben Moses Mosconi ("pseudo-Josephus") of Ohrid in Serbian Macedonia from Hebrew into Arabic at an unspecified date (published in Livorno in 1886), is hardly a candidate, although Mosconi did travel to the Maghrib and to Perpignan *ca.* 1360 – see Sarton, *IHS*, III:2, p. 1451. Another non-candidate is Abū or Ibn Mas'ūd of Seville, head of Maghribī *madrasa*, who commissioned a book on magic, apparently at the end of the 14th century – *ibid.*, III:2, p. 1521.

reasonable care for the correct latitudes. He was also a skilled engraver, as is apparent from his inscription on the boss of the shackle. He was needy (*faqīr*) in the standard Islamic sense, namely, needy of the mercy of God, and the use of this term indicates that he engraved the inscription himself. The epithet *al-wāthiq*, "he who trusts", is usually applied to rulers,[268] but even they, in Islamic civilisation, trusted in God, here called *al-malik al-ma'būd* in order to rhyme with Mas'ūd.[269] The term *al-malik* is one of the names of God,[270] but the expression *al-malik al-ma'būd*, "the King who is to be worshipped", is neither *Qur'ān*ic nor is it attested in the statements attributed to the Prophet Muḥammad; indeed, it is not happily Islamic. Nor is it Biblical, although the choice of words is vaguely reminiscent of the *Psalms*.[271] The word *ma'būd* is, however, used to refer to God by the famous poet and religious philosopher Jūdah Ha-Lēvī (b. Tudela, *ca.* 1075, *fl.* Granada then Toledo, d. Cairo, 1141) in his discussion of the First Commandment: he renders Hebrew *elohekha*, "your God", by *ma'būduka*, "the object of your worship".[272] In passing we note the

[268] Indeed, the Ḥafṣid ruler of Tunisia in the middle of the second half of the 13th century was called Abū Zakariyā' Yaḥyā al-Wāthiq – see de Zambaur, *Manuel*, p. 74; Bosworth, *Islamic Dynasties*, new edn., pp. 45-46; and the article "Ḥafṣid" in EI_2, especially p. 67a. See also Brockelmann, *GAL*, SII, p. 232, for a mid-14th-century Zaydī Imām of the Yemen named *al-Wāthiq bi-llāh* al-Muṭahhar. The same title was held by an Abbasid and an Almohad ruler.

[269] Yet the two lines do not display a poetic metre in the traditional sense of Arabic poetry (see the EI_2 article "'Arūḍ").

[270] Articles "Malik" [= king] and "al-Asmā' al-ḥusnā" [= the 99 names of God"], (no. 4), in EI_2.

[271] As a curiosity we note that the terminology is even more reminiscent of the Protestant hymn beginning:

"O **Worship** the **King**, all glorious above,"

and with a line in the fifth verse:

"In Thee do we **trust**, nor find Thee to fail."

These words were composed in 1833 by Robert Grant, and are supposedly based on Psalm 104.

[272] I owe this information to the kindness of Tzvi Langermann. See his "Science and the *Kuzari*", p. 500, n. 5.

existence of an unpretentious 14th-century Mamluk brass box with silver inlay in the Metropolitan Museum of Art in New York[273] which bears an inscription apparently identifiying the maker and the person who commissioned the piece: the latter is named *al-Wāthiq bi-'l-malik al-walī* ibn Muḥammad. Here again the expression *al-malik al-walī*, "the king who is the protector", that is, God, is not *Qur'ān*ic, although *al-walī* this time *is* one of the 99 names of God.[274]

There is a flavour of dissimulation in Mas'ūd's inscription of ownership, as if he did not want to mention the name of God. Neither, as we have noted, did he engrave the name of Mecca on the plate for the latitude of the holiest city in Islam; nor did he label the special markings for the times of Muslim prayer on the plates for Algiers, Mecca and Jerusalem. Whilst any *mudéjar* in the 14th or 15th century would try to be careful with what he wrote, we may have here, in what he did not write, a vague hint that he was a prisoner of the Christians.[275]

No individual named Mas'ūd from al-Andalus with an interest in astronomy is known. But there is one man Mas'ūd who was the father of an astronomer, and the family had both an Andalusī and a Maghribī connection.[276] Also the date of the father would correspond to a dating of the

[273] Atıl, *Mamluk Art*, p. 104, no. 36 (The Edward C. Moore Collection, inv. no. 91.1.538). The inscription supposedly reads: *mimmā 'amila[hu] bi-rasm al-wāthiq bi- 'l-malik al-walī ibn Muḥammad Muḥammad ibn 'Alī al-Ḥamawī al-muwaqqit bi-'l-jāmi' al-umawī*, which, if it is correct, could be taken as meaning "This was made by Muḥammad ibn 'Alī al-Ḥamawī, the professional timekeeper at the Umayyad Mosque (in Damascus), by order of *al-Wāthiq bi-'l-malik al-walī* ibn Muḥammad". The work is of the "provincial type of metalwork available to the middle classes" (Atıl). The maker is not listed in Mayer, *Islamic Metalworkers*, and is unknown to the history of Islamic astronomy. The client has not been identified.

[274] See the article "al-Asmā' al-ḥusnā" in EI_2 (cited in n. 270), (no. 56).

[275] The veiled inscriptions of Muslim prisoners and slaves under Christian domination were in general less subtle – see van Koningsveld, "Muslim Captives".

[276] A certain 'Izz al-Dīn 'Abd al-'Azīz ibn Sa'd al-Dīn Mas'ūd ibn 'Izz al-Dīn 'Abd al-'Azīz al-Tilimsānī al-Mālikī was *imām* and *muwaqqit* in the cities of Fez, Tunis, Jerusalem and Damascus. (The epithet al-Tilimsānī indicates that he hailed from Tlemcen.) He oversaw the copying of MS Escorial ar. 932 of the astronomical handbook of Ibn Abi 'l-Shukr al-Maghribī (compiled in Damascus in 1258) in Tunis in the year 797 H [= 1394/95], and his name and these affiliations are given in this form in a colophon (fol.

astrolabe to the mid 14th century. The family appears to have been Andalusī in origin. The son, possibly born in Tlemcen, some 500 km WSW of Algiers, was *imām* and *muwaqqit* in Fez, Tunis, Jerusalem and Damascus, and in the last-mentioned city he became a chief judge of the Mālikī legal school. Andalusī and Maghribī emigrants to Syria would have been adherents of the Mālikī school, which was predominant in al-Andalus but barely represented in Syria. It is a far cry from an astrolabe-

57v). See Samsó, "Maghribī *Zījes*", p. 96; this information is overlooked in the description of the manuscript in *Escorial Catalogue B*, pp. 43-44.

Also, Ibn Mas'ūd was the author of a treatise on the quadrant with trigonometric grid (see the article "Rub'" in EI_2) compiled in Cairo in the year 795 H [= 1392/93] (on the context see King, "Mamluk Astronomy"). This is known from a unique copy, MS Escorial ar. 918/14 – see *Escorial Catalogue A*, p. 353; *Escorial Catalogue B*, p. 24 (also pp. 17 and 23); *Cairo ENL Survey*, p. 66 (no. C46); and Rosenfeld & Matvievskaya, *MAMS*, II, p. 324, no. 271a. The manuscript was copied in Maghribī script in the year 888 H [= 1483/84]. The same 'Abd al-'Azīz is mentioned in a later Tunisian treatise on astronomical instrumentation (*Cairo ENL Survey*, p. 141, no. F39, on Abū Ja'far al-Tūzarī, *fl.* Tunis *ca.* 1450), and there is a quadrant made by him in 774 H [= 1372/73] preserved in the National Museum, Damascus.

Now the remarks in MS Escorial ar. 918 mention that 'Abd al-'Azīz was the chief Mālikite judge (*aqḍa 'l-quḍāt*) in Damascus. The Mālikī legal school was not strong in Syria (see "al-Mālikiyya" in EI_2), and it is somewhat surprising that there was a Mālikite official there with this prestigious title. But it was the major school in al-Andalus, and numerous Andalusī scholars emigrated to Syria at the time of the *Reconquista*. And in this manuscript 'Abd al-'Azīz is referred to by an Andalusī name, Ibn *F-r-m-j-h* or *F-r-m-y-j-h* (vowelling uncertain), possibly derived from the Spanish *bermejo*, meaning "of a bright reddish colour". The first catalogue-entries for this Escorial manuscript provided the modern literature with an "Abdelaziz Massudus Hispalensis" (*Escorial Catalogue A*, p. 353) from whom developed an "Abdelaziz Abenmasud el Ixbilí (from Seville)" (Sánchez Pérez, *Biografías*, p. 34, also Vera, *MME*, p. 141); and an "'Abd al-'Azīz b. Mas'ūd al-Ishbīlī (XIIe s.)" (Lamrabet, *Mathématiques maghrébines*, p. 38, no. 203), sometimes, as now in Rosenfeld & Matvievskaya, *MAMS*, with the additional fiction that he died in 1132 A.D.

Most of the above information is found in a recent doctoral thesis by M. Aguiar Aguilar, in which the author and his treatise on the sine quadrant are investigated for the first time (Aguiar Aguilar, "Tratado árabe oriental", pp. 97-98, *eadem*, "En torno a 'Abd al-'Azīz b. Mas'ūd", and *eadem*, *Tratado de Ibn Mas'ūd*, pp. 461-468). There is more to be said, but neither this Mas'ūd nor his son have been found yet in the available biographical works (including some mentioned, for example, in Fagnan, "Tabakāt malekites").

maker in al-Andalus to a judge in Damascus, but in trying to identify Mas'ūd we are indeed grasping at straws.

Mas'ūd's engraving of the names of the signs and of the month-names and their decoration remains somewhat problematic. In fact, it is not very professional within the framework of the high standards of Islamic astrolabe engraving. Rather his work shows a certain amount of calligraphic licence and is more typical of inscriptions one might find, say, woven on textiles.[277] But his contribution is of extreme historical interest, for we are dealing with the only example of the influence of a local dialect on Arabic inscriptions on an astronomical instrument. And in his decoration of the cartouches Mas'ūd was perhaps over enthusiastic. No criticism is intended here: in the workshops of the instrument-makers of the Middle Ages we do not expect the rigorous, and in many respects tedious, discipline of the madrasas and the monastic scriptoria. People simply did the best they could under the circumstances. We may also compare European instrument-makers who left off the names of stars on astrolabe retes because they could not understand the Arabic originals (#3042, #161 and #167)[278] or who confused the latitudes on the plates (#3915 and #4523),[279] or who left out both the star-names and the latitudes (#169).[280] An example of the very kind of Andalusī astrolabe which might have inspired Mas'ūd is preserved for us, namely, #116, made in Toledo in 420 H [= 1029/30] by Muḥammad ibn al-Ṣaffār. It even bears

[277] Compare, for example, the text *al-baraka laka mina llāh*, "The blessings that you have are from God", on the 13th-century silk textile fragment in the Instituto de Valencia de Don Juan, Madrid, illustrated in *Granada-New York 1992 Exhibition Catalogue*, p. 111, fig. 7 (see already n. 255 above). Here the text is written on the left-hand side of a series of semicircular arcs open at the bottom with the *sukūn* of *alØ-baraka* on the line before the *al-*, and there is a redundant *sukūn* above or, rather, following the word *allāh*. The inscription is repeated in mirror-image on the right.

[278] On the first see Kunitzsch & Dekker, "Stars on the Carolingian Astrolabe". On the second, whose present location is unknown, only the description in Gunther, *Astrolabes*, II, p. 306 (no. 161), is available. No illustrations of the third have been published.

[279] On #3915 see nn. 26 and 179 above, and on #4523 see n.180.

[280] On #169 (n. 178) see King, "Medieval Italian Non-Standard Astrolabe", especially §§B4-5 and B8.

additional markings in Hebrew script that appear to have been added in Toledo.

e) The Algiers connection

Algiers was founded in the 10th century on the ruins of the Roman city of Icosium.[281] A significant mosque was built there in the 13th century. A traveller of that century, al-ʻAbdarī, mentioned the exceptionally beautiful natural setting of Algiers and the imposing solidity of its ramparts, but added that there were no scholars there, indeed that his search for a single one was like looking for a horse full of camels' eggs.[282] He was comparing Algiers with Tlemcen, Bougie, Bône and Tunis, which did have an intellectual life, and indeed even a scientific life.[283]

Although it appears that Masʻūd made this engraving in Christian Spain rather than in Algiers, that city was clearly close to his heart. Now how could he have known that the latitude was around 36°? In fact the latitude (correctly 36°50′) is given as 35;30° in the geographical tables of Ibn al-Zayyāt (al-Andalus, d. 1058) and al-Marrākushī (of Moroccan origin, *fl.* Cairo *ca.* 1280).[284] It may be that 35;30° was indeed the very latitude used by Masʻūd for his plate. Likewise, he probably used 21;40° for the latitude of Mecca, the value that was most popular amongst Andalusī astrolabe-makers.[285]

The astronomical markings on this plate serve not only Algiers, but also the middle of the fourth climate of Antiquity.[286] Plates for 36° with

[281] See the article "al-Djazā'ir" [= Algiers] in EI_2.

[282] Cherbonneau, "Voyage d'El-Abdéry", A, pp. 157-158 (pp. 14-15 of the reprint), and B, pp. 54-55 (pp. 38-39 of the reprint).

[283] On the history of astronomy and mathematics in the Maghrib see King, "Astronomy in the Maghrib", and Djebbar, *Études*, respectively.

[284] Kennedy & Kennedy, *Islamic Geographical Coordinates*, p. 19. On the two sources see *ibid.*, pp. xxv (*sub* MAR) and xxxvii (*sub* ZAY).

[285] This value was sometimes approximated to 22° or 21;30°. See King, "Geography of Astrolabes", App. 1c.

[286] See n. 36 above.

this in mind were common on Islamic and some European astrolabes.[287] Western Islamic astrolabes tended to have numerous place-names associated with the latitude on each plate, 35;20° usually being linked with Ceuta (Sabta) and 36° with Almería. But although some even from before *ca.* 1100 do feature Kairouan, Tunis, Tangiers and Ceuta, none bears markings for Algiers. In fact, only one piece from before *ca.* 1600 (#4046) has markings for Algiers, albeit with the absurd latitude 33;20°.

But what was Mas'ūd's association with Algiers? One possibility is that he, a Muslim, planned to flee Christian-dominated Northern Spain for Algiers. A *hijra* or "breaking of ties" was advocated for all Muslims living under Christian domination.[288] The medieval population of Algiers consisted in part of refugees who had fled from the Christian reconquest of al-Andalus, and many of them established themselves as corsairs in Algiers. The first Jewish refugees from Spain arrived in Algiers in 1391.[289] In 1510 the Spaniards imposed a levy on the city and occupied the neighbouring islands, in order to suppress the corsairs.[290] This was taken by the Ottoman Turks as an invitation to liberate Algiers from both the Spaniards and the locals.

f) The origin of the astrolabe

Any attempt to understand how the instrument came to acquire its present form can only be partially successful.[291] The following reconstruction is at best hypothetical.

[287] Thus, for example, on #2572 all of the plates serve specific localities, but that for 36° is marked for Almería and the 4th climate.

[288] Article "Mudéjar" in *EI*$_2$, cols. 288a-b. See also Buzineb, "Respuestas", on two *fatwās* or religio-legal pronouncements dated 1392 and 1504 by Maghribī jurisprudents to this effect.

[289] Article "Algiers" in *EJ*.

[290] Article "Al-Djazā'ir" [= Algiers] in *EI*$_2$, p. 520a.

[291] A. J. Turner and E. Savage-Smith (in *Nancy 28.06.1998 Pamphlet*) suggested, largely on the basis of the Syrian-type throne, the Syrian-type silver cartouches, the plate for [36°], which would serve Aleppo, and the Andalusī-type rete, that the instrument must have been made in Egypt or Syria or even further east in Iraq or Iran by an Andalusī or

The instrument was begun in some centre of Christian Spanish culture in the 14th century; Toledo seems the most likely choice, although Saragossa is also a possibility. A Christian and a Jew collaborated on the construction, the only definitive traceable input of the latter being the latitudes scratched in Hebrew on the plates. It is also possible that there was only one individual involved, perhaps a Christianized Jew. An unusual Andalusī-type design was chosen for the throne and for the rete, and an Andalusī, perhaps especially an Andalusī Jewish technique of silver inlay. With the inscriptions on the back not completed, the instrument changed hands. A Spanish Arab, a *mudéjar*, named Mas'ūd, with an especial interest in Algiers, added the main Arabic inscriptions, providing the names of the zodiacal signs and the months with orthographical symbols perhaps inspired by an earlier Andalusī astrolabe. His engraving shows distinct Spanish Arabic influence. In addition he substituted one of the plates for a new one serving Algiers and Mecca and engraved the inscription on the boss of the shackle identifying himself as the owner. He appears to have deliberately omitted the name of God in this inscription, the name of Mecca on his new plate, and any identification of the purpose behind the special curves for the times of Muslim prayer on his plate for Algiers and Mecca and and on the original plate for Jerusalem. Perhaps he intended to take the instrument to Algiers, and maybe someone there added the second layer of Arabic star-names. But it may be the astrolabe was never taken to Algiers, for a couple of hundred years later it was in Northern or Eastern France, where in the 16th century someone added the numbers on the outer rim.

The hypothesis that the astrolabe was made but not completed by a European and that it *later* fell into the hands of an Arab, namely Mas'ūd, who added the first layer of Arabic star-names as well as the plate for Algiers and Mecca, would mean that the instrument in its uncompleted form was in circulation. Other questions have to be addressed but cannot

Maghribī instrument-maker, but not completed, and that the "Latin" inscriptions were added later in Europe. To counter this one only need point out that that the throne is an attested earlier Andalusī design, that the silver cartouches are quite different from the silver inlay on known Syrian (and Egyptian) astrolabes, and that the markings for 36° and $21\frac{1}{2}$° are not by the same maker as the mater, rete and three other plates.

be answered. If Mas'ūd was a Christian or a Christian convert from Islam, then why did he engrave a plate for the latitude of Mecca? If Mas'ūd was a Muslim, then why did he use the unusual expression *al-malik al-ma'būd* to rhyme with his name? And a particularly vexing question is: why did Mas'ūd engrave a plate specifically for Algiers?

Various other explanations are conceivable but not particularly convincing given the lack of concrete evidence. Perhaps the astrolabe, not yet completed, was taken in the 16th century by a Spaniard to sea and the pair captured by corsairs from Algiers. The Arabic additions might then have been made in Algiers itself. This would at least explain why the Arabic script looks later than the 14th century and how there came to be additional markings for Algiers (but no additional Arabic inscription for, say, Toledo). But one would hardly expect a corsair or his patron to engrave the names on the back properly. And there was no known astronomical activity in Algiers before the Ottoman period.[292] Our Mas'ūd, however, was competent in Arabic and in astrolabe-construction, as we can see from the inscription on the boss of the shackle and from the latitudes he used for his plate. Besides, if he made the additions in Algiers, there would have been no reason whatsowever not to add the name of Mecca and the names of the prayers.

The astrolabe is a testimonial to the lives and fates of three, perhaps only two individuals; indeed, on no other historical instrument are the lives and aspirations and fates of individuals so poignantly portrayed. One was a Jew, perhaps involved only in the laying out of the astronomical markings on the piece. The second, the person who did the Latin engraving, was maybe identical to the first, but if he was not, then he may have been a Spanish Christian, possibly a convert from Judaism. He seems to have died or been beset by some other disaster before he finished the piece. The other was a Muslim Arab, a *mudéjar*, who seems to have been planning to return to the Muslim world as religious duty behoved him, specifically to Algiers. He finished the astrolabe and certainly planned to take it with him.

[292] See n. 283 above. In *Cairo ENL Survey*, p. 145 (no. F66), there is information on a late (17th-century?) recension for Algiers of the 14th-century astronomical tables of Ibn al-Shāṭir of Damascus (on whom see the article in *DSB*).

There are still many questions surrounding this astrolabe to which it would be satisfying to know the answers. Part of the problem is that there are so few instruments with which we can compare this piece.[293] The most tantalizing questions relate to the person(s) who started to make it and the one named Mas'ūd who finished it. All manner of scientific, technological, epigraphic and art-historical investigations will not necessarily bring us any closer to the answers. But there is hope that further research might cast more light on the provenance of this object, and this would be welcome, for it is surely one of the most interesting astrolabes surviving from the Middle Ages.

Acknowledgments: I wish to acknowledge the generosity of the curators of the various museums and the owners of private collections in which the instruments discussed in this study are preserved. For illustrations I am indebted first and foremost to Jeremy Collins, formerly of Christie's, London, who provided photographs of the Spanish astrolabe. Other photos were kindly made available by the The Adler Planetarium, Chicago; the Museum of the History of Science at Oxford, and the Bibliothèque Nationale de France, Paris. During the course of the research for this study I had the pleasure and privilege of using the facilities of the Biblioteca Nacional in Madrid and the Widener Library at Harvard University. Grateful thanks are also due to various friends and colleagues – including Maravillas Aguiar Aguilar (La Laguna, Tenerife), Guy Beaujouan (Paris), François Charette (Frankfurt *thumma* Cambridge, Mass.), Karine Chemla (Paris), Benno van Dalen (Frankfurt), Koenraad van Cleempoel (Antwerp), Federico Corriente (Saragossa), Reinhard Glasemann (Frankfurt), Martin Hellmann (Heidelberg), Peter Sjord van Koninksveld (Leiden), Paul Kunitzsch (Munich), Y.

[293] Other European instruments from medieval Spain have not fared well in the modern literature. As already noted, the oldest surviving European astrolabe, #3042, has been the object of much controversy, and two other important pieces from Catalonia, #416 and #3053, are not even published. General historians of science cannot take instruments seriously until the basic research has been done. Thus, for example, in Glick, "Jewish Contribution to Science in Medieval Spain", the choice of instruments used to illustrate that article was unfortunate: fig. 22 on p. 82 shows a medieval astrolabe with Hebrew inscriptions which is probably Italian (#159); fig. 21A on p. 88 shows a Renaissance astrolabe datable *ca.* 1500 and probably from Vienna, not from Spain as maintained by Gunther (#164); and Fig. 21B on p. 89 shows an unsigned, undated Maghribī or Andalusī astrolabe fitted with a most unusual Ottoman replacement rete (#3643).

Tzvi Langermann (Jerusalem), Martina Müller-Wiener (Bonn), Julio Samsó (Barcelona), Eleanor Sims and Ernst Grube (London), Burkhard Stautz (Huenfelden), Anthony Turner (Le Mesnil-le-Roy), Annette Weber and Johannes Wachten (Jüdisches Museum, Frankfurt), and Juan Zozaya (Madrid) – for their assistance on various aspects of this study and for their encouragement. Mine alone is the responsibility for any remaining errors and misinterpretations.

Appendix A
Instruments cited

Note: Each instrument has been assigned a number (here prefixed by #), continuing the tradition started by R. T. Gunther and upheld by Derek de Solla Price. The vast majority of the instruments listed below are described in the catalogue in preparation in Frankfurt. Various instruments mentioned only in passing are not listed here, and for these the reader must have recourse to Price *et al.*, *Checklist*. The star-positions on numerous individual astrolabes are investigated in Stautz, *Untersuchungen*.

#101 Unsigned, undated 10th-century astrolabe from Iraq, with purportedly medieval European markings on the back – Florence, Istituto e Museo di Storia della Scienza, inv. no. 1113 – Gunther, *Astrolabes*, I, pp. 230-231 (no. 101: "The Astrolabe of Pope Sylvester II", already expresses reservations); García Franco, *Astrolabios en España*, pp. 131-160 (no. 3, an electrotype copy: "Astrolabio del siglo XIII, reproducción del de Alfonso el Sabio"); *Santa Cruz 1985 Exhibition Catalogue*, pp. 78-79 (no. "astrolabio de autor desconocido"); *Cádiz-Algeciras 1995 Exhibition Catalogue*, p. 60 ("Astrolabio de Alfonso X el Sabio"); *Florence MSS Catalogue*, p. 8, no. 2 ("La tradizione lo fa risalire a Carlo Magno."); and King, "Astronomical Instruments between East and West", p. 171 (introduces 19th-century faker for the markings on the back).

#103 Astrolabe by ʻAbd al-Karīm al-Miṣrī dated 625 H [= 1227/28], with later replacement rete – Oxford, Museum of the History of Science, inv. no. IC 103 – see Gunther, *Astrolabes*, I, pp. 233-236 (no. 103).

#104 Astrolabe by 'Abd al-Karīm al-Miṣrī, made in Damascus (?) in 633 H [= 1235/36] – London, British Museum, inv. no. OA 1855, 7-9.1 – see Gunther, *Astrolabes*, I, pp. 236-237 (no. 104).

#106 Universal plate by Ibrāhīm al-Dimashqī, made in Cairo (?) in 699 H [= 1299/1300] – London, British Museum, inv. no. OA 1890, 3-15.3 – see Gunther, *Astrolabes*, I, p. 238 (no. 106).

#107 Astrolabic plate made by Ḥasan ibn 'Alī in Cairo in 681 H [= 1282/83] – Oxford, Museum of the History of Science, inv. no. IC 107 – see Gunther, *Astrolabes*, I, pp. 239-240 (no. 107).

#109 Astrolabe made by the Yemeni Sultan al-Ashraf in 695 H [= 1291] – New York, Metropolitan Museum of Art, inv. no. 91.1.535 – see Gunther, *Astrolabes*, I, p. 243 (no. 109) and pl. LVIb, and the detailed description in King, "Astrolabe of the Yemeni Sultan al-Ashraf".

#110=#135 10th-century Andalusī astrolabe, with later markings by a European – London, British Museum, inv. no. OA+371 – see Gunther, *Astrolabes*, I, p. 244 (no. 110), and p. 280 (no. 135), inadvertently listed twice; and King, "Earliest European Astrolabe", fig. 3.

#111 Astrolabe by Ḥāmid ibn Khiḍr al-Khujandī, made in Baghdad in 374 H [= 984/85]. with quatrefoil decoration on the rete – Kuwait, private collection – see the detailed description in King, "Kuwait Astrolabes", pp. 80 and 82-89, also the illustrations in *idem*, *Mecca-Centred World-Maps*, pp. 18-19.

#116 Astrolabe by Muḥammad ibn al-Ṣaffār of Toledo, dated 420 H [= 1029/30] – Berlin, Staatsbibliothek, Preußischer Kulturbesitz, Orientabteilung, inv. no. 6567 (Sprenger 2050) – see the detailed description in Woepcke, "Arabisches Astrolabium"; Gunther, *Astrolabes*, I, pp. 251-252 (no. 116), based on Woepcke; and on the additional inscriptions, Maier, "Romanische Monatsnamen", B, p. 260. See here Fig. 14.

#117 Astrolabe by Ibrāhīm ibn Sa'īd al-Sahlī, dated Toledo, 459 H [= 1066/67] – Madrid, Museo Arqueológico Nacional, inv. no. 50762 – see the detailed description in García Franco, *Astrolabios en España*, pp. 229-235 (no. 12); and also Gunther, *Astrolabes*, I, pp. 252-253 (no. 117), and *Santa Cruz 1985 Exhibition Catalogue*, pp. 80-81 (colour illustrations of the front and back).

#123 Astrolabe by Ibrāhīm ibn Sa'īd, made in Valencia, 463 H [= 1070/71] – now in the Osservatorio, Rome – unpublished, see Gunther, *Astrolabes*, I, p. 263 (no. 123).

#130,134, 139,153 — Various astrolabes by al-Khamā'irī of Seville *ca.* 1220 – see Gunther, *Astrolabes*, I.

#134 — See #130.

#135 — See #110.

#137 — Astrolabe with circus-figures on the rete, made in Syria by al-Sahl al-Nīsābūrī, datable between *ca.* 1180 and *ca.* 1280 – Nuremberg, Germanisches Nationalmuseum, inv. no. WI 20 – see the detailed descriptions in *Nuremberg GNM 1992-93 Exhibition Catalogue*, pp. 570-574 (no. 1.71); and *Paris IMA 1993-94 Exhibition Catalogue*, pp. 432-434 (no. 329).

#137 *bis* — See #550.

#139 — See #130.

#140 — The quintuply-universal astrolabe of Ibn al-Sarrāj, Aleppo, 729 H [= 1328/29] – Athens, Benaki Museum, inv. no. 13178 – see Gunther, *Astrolabes*, I, pp. 285-286 (no. 140); King, *Studies*, B-IX; *Paris IMA 1993-94 Exhibition Catalogue*, pp. 434-435 (no. 330); and a forthcoming book by the present author and François Charette.

#153 — See #130.

#154 — Andalusī astrolabe by Muḥammad ibn Yūsuf ibn Ḥātim dated 638 H [= 1240/41] – Chicago, Ill., Adler Planetarium, inv. no. M-36 – see Gunther, *Astrolabes*, I, pp. 300-301 (no. 154), misdated to 1747; and *Chicago AP Catalogue*, II (forthcoming). See here Fig. 10.

#158 — Astrolabe with Hebrew incriptions, Bologna (?), *ca.* 1400 (?) (see no. #159) – London, British Museum, inv. no. 93 6-16 3 – Gunther, *Astrolabes*, II, p. 304 (no. 158); *London BM Catalogue*, p. 113-114 (no. 328) and pl. LIIIa; and also Goldstein, "Hebrew Astrolabe".

#159 — Degenerate astrolabe with Hebrew inscriptions, Bologna (?), *ca.* 1400 (?), with plates labelled for Bologna and Paris – Chicago, Ill., Adler Planetarium, inv. no. M-20 – Gunther, *Astrolabes*, II, p. 304 (no. 159); Goldstein, "Hebrew Astrolabe"; and *Chicago AP Catalogue*, II, pp. 58-60 (no. 7).

#161 — "Hispano-Mauresque" astrolabe, with "distinctly oriental appearance", no star-names on the rete, with plates for the climates and equinox at March 15 – present location unknown, *ca.* 1930 in the collection of Sir J. Findlay – see Gunther, *Astrolabes*, II, p. 306 (no. 161).

#162 Catalan astrolabe from *ca.* 1300 with a rectangular frame and decorative quatrefoil on the rete – London, Society of Antiquaries – see Gunther, *Astrolabes*, II, pp. 306-309 (no. 162), and the detailed description in King & Maier, "Catalan Astrolabe".

#163 A French astrolabe, not Spanish as claimed by Gunther.

#164 Astrolabe with quatrefoil decoration and plates for latitudes 40°, 42°, 44°, 45°, 48° and 50°, attributable to the Vienna school (the elongated horizontal form of the final *s* is very reminiscent of Hans Dorn of Vienna *ca.* 1480) – Chicago, Ill., Adler Planetarium, inv. no. M-28 – see Gunther, *Astrolabes*, II, pp. 311-312 (no. 164, under Spanish astrolabes) and miniature reproduction of front on pl. LXX; Glick, "Jewish Contribution to Science in Medieval Spain", fig. 21A on p. 88; and *Chicago AP Catalogue*, II, pp. 49-52 (no. 4, again with the provenance as Spain).

#165 Astrolabe made in Saragossa in 1558 – Oxford, Museum of the History of Science, inv. no. IC 165 – see Gunther, *Astrolabes*, II, pp. 312-315 (no. 165) and pl. LXX.

#166 Italian astrolabe with plates for the climates – Oxford, Museum of the History of Science, inv. no. IC 166 – see Gunther, *Astrolabes*, II, pp. 316-317 (no. 166).

#167 Medieval Italian (?) astrolabe – London, British Museum, inv. no. 67 7-5 22 – see Gunther, *Astrolabes*, II, p. 317 (no. 167), and *London BM Catalogue*, p. 114 (no. 329).

#169 Italian non-standard astrolabe from *ca.* 1300, with markings only for latitude 24° (second climate), suggesting that this may be a 19th-century copy of such an instrument – Oxford, Museum of the History of Science, inv. no. IC 169 – see Gunther, *Astrolabes*, pp. 319-320 (no. 169); and the detailed description in King, "Medieval Italian Non-Standard Astrolabe".

#190 Astrolabic plate for latitude 48;50° (Paris), 14th century (?) – London, Victoria and Albert Museum, inv. no. M. 128.1923 – unpublished; see Gunther, *Astrolabes*, II, p. 349 (no. 190); *Instrument Directory*, p. 27, figs. 7A-B (front and back); also King, *Ciphers of the Monks*, pp. 391-392.

#191 Composite medieval European astrolabe, with an Italian mater, Andalusī-style rete (reworked?), and plates for Saragossa and Paris – Oxford, Museum of the History of Science, inv. no. IC 191 – Gunther, *Astrolabes*, II, pp. 340-341 (no. 191).

#198 Northern French astrolabe from *ca.* 1350 with luni-solar gear mechanism – London, Science Museum, inv. no. 1880.32 – see

Gunther, *Astrolabes*, II, p. 347 (no. 198), and King, *Ciphers of the Monks*, pp. 398-399, 402-403, *etc*. (see p. 439).

#202 Picard astrolabe from *ca*. 1350 with numbers marked in monastic ciphers – private collection – see Gunther, *Astrolabes*, II, p. 349 (no. 202), and the detailed description in King, *Ciphers of the Monks*, pp. 131-151 and 406-419.

#203 Illustrations of the rete and back of an astrolabe in the treatise *L'usaige de l'astrolabe* by Dominique Jacquinot, printed in Paris in 1545 – see Gunther, *Astrolabes*, II, pp. 350-352 (no. 203).

#213 Highly unusual medieval astrolabe in iron, of uncertain date and provenance, with latitude grid around the ecliptic on the rete and inlaid silver illustrations of the zodiacal signs on the back – *ca*. 1930 in the possession of Whitney Warren; present location unknown – see Culver, "Early European Instruments", p. 34, for an illustration of the front, and Gunther, *Astrolabes*, II, pp. 361-362 (no. 213); Gunther's dating to the end of the 16th century is much too late.

#290 English astrolabe from *ca*. 1300 with highly-developed quatrefoil decoration on the rete – London, British Museum, inv. no. MLA SL54 – see Gunther, *Astrolabes*, II, pp. 463-465 (no. 290).

#291 Unsigned English astrolabe dated 1326 – London, British Museum, inv. no. 1909 6-17 1 – see Gunther, *Astrolabes*, II, pp. 465-467 (no. 291); and *London BM Catalogue*, pp. 112-113 (no. 325), and pl. LI.

#292 English astrolabe signed "Blakenei" and dated 1342 – London, British Museum, inv. no. 53 11-4 1 – see Gunther, *Astrolabes*, II, pp. 468-469 (no. 292); and *London BM Catalogue*, p. 113 (no. 326) and pl. LII.

#293 Medieval English astrolabe with additional Hebrew inscriptions (owner's mark?) on the throne – London, Victoria & Albert Museum, inv. no. 1880.26 – see Gunther, *Astrolabes*, pp. 469-471 (no. 293).

#300 Northern French (?) or English (?) astrolabe from *ca*. 1300 – Oxford, Museum of the History of Science, inv. no. IC 300 – see Gunther, *Astrolabes*, II, pp. 477-478 (no. 300), and King, "Earliest European Astrolabe", fig. 12. See here Fig. 13.

#304 Unsigned, undated English astrolabe – Washington, D.C., National Museum of American History, inv. no. 316758 – see Gunther, *Astrolabes*, II, p. 483 (no. 304) and pl. CXXXIV; and *Washington NMAH Catalogue*, pp. 13 and 150-151 (no. 304).

#416	Catalan astrolabe from *ca.* 1300 with a Y-shaped frame on the rete – Greenwich, National Maritime Museum, inv. no. ASTO552 = A21/1936-21C – see King & Maier, "Catalan Astrolabe", pp. 694-695, n. 60, King, "Earliest European Astrolabe", fig. 14; and the forthcoming description by Koenraad van Cleempoel in *Greenwich Astrolabe Catalogue*. See also n. 16.
#420	Early medieval European astrolabe, perhaps the earliest after #3042, origin uncertain – Greenwich, National Maritime Museum, inv. no. ASTO558 = A27/1936-4C – illustrated in King, "Earliest European Astrolabe", fig. 9; see the forthcoming description by Koenraad van Cleempoel in *Greenwich Astrolabe Catalogue*.
#428=#625	French astrolabe from *ca.* 1300 – Greenwich, National Maritime Museum, inv. no. ASTO570 = A39/NA1938-1661C – see *Greenwich NMM Handlist*, p. 48, for an illustration of the front; and the forthcoming description by Koenraad van Cleempoel in *Greenwich Astrolabe Catalogue*.
#457	Medieval English astrolabe – Liège, Musée de la vie wallonne, inv. no. 400 – unpublished; illustrated in Michel, *Traité de l'astrolabe*, pl. III.
#460	Astrolabe from the workshop of Jean Fusoris, Paris, *ca.* 1400, with inscriptions removed and replaced by 18th- or 19th-century Arabic inscriptions (probably in Egypt) – Antwerp, Nationaal Scheepvaart-museum, inv. no. A.S. 43.9.127 – see Michel, *Traité de l'astrolabe*, pl. IV; and *Brussels SG 1984 Exhibition Catalogue*, pp. 37-38 (no. 8).
#493	14th-century Italian astrolabe – Florence, Museo di Storia della Scienza, inv. no. 1107 – detailed description in King, "Urbino Astrolabe", pp. 127-129; see also *idem*, "Star-Names on Three Medieval Astrolabes", pp. 320-323.
#546	14th-century French quatrefoil astrolabe – Paris, private collection – unpublished.
#548	14th-century Italian astrolabe with additional 15th-century markings by Henricus de Hollandia – Nuremberg, Germanisches Nationalmuseum, inv. no. WI 6 – see *Nuremberg GNM 1992-93 Exhibition Catalogue*, II, pp. 578-581 (no. 1.74).
#549	Unsigned astrolabe of the Vienna school dated 1457 – Nuremberg, Germanisches Nationalmuseum, inv. no. WI 129 – see *Nuremberg GNM 1992-93 Exhibition Catalogue*, II, pp. 582-586 (no. 1.75).
#550	German astrolabic plate dated 1468 – Nuremberg, Germanisches Nationalmuseum, inv. no. WI 5 – see Gunther, *Astrolabes*, I, pp.

280-281 (no. 137 – confused!) and more especially *Nuremberg GNM 1992-93 Exhibition Catalogue*, II, pp. 589-592 (no. 1.77).

#555 Unsigned, undated astrolabe in the tradition of the Arsenius brothers – Nuremberg, Germanisches Nationalmuseum, inv. no. WI 1164 – see *Nuremberg GNM 1992-93 Exhibition Catalogue*, pp. 598-600 (no. 1.82). See here Fig. 11.

#558 Early medieval European astrolabe of uncertain provenance – Nuremberg, Germanisches Nationalmuseum, inv. no. WI 282 – see *Nuremberg GNM 1992-93 Exhibition Catalogue*, II, pp. 574-576 (no. 1.72).

#621 Composite medieval European (Italian?) astrolabe with a very early rim, rete and plates, and a back from an astrolabe with Hebrew inscriptions – Munich, Deutsches Museum, inv. no. 5178 – see *Munich Astrolabe Catalogue*, pp. 161-176 (no. 2), also King, "Earliest European Astrolabe", fig. 13.

#625 See #428.

#640 Astrolabe presented by Regiomontanus to his patron Bessarion in 1462 – private collection – see most recently King & Turner, "Bessarion's Astrolabe".

#1077 Astrolabe made in Fez by ʿUthmān ibn ʿAbdallāh al-Ṣaffār in 699 H [= 1299/1300] – Florence, Istituto e Museo di Storia della Scienza, inv. no. 1109 – unpublished; see Mayer, *Islamic Astrolabists*, p. 84 and pl. IVb, and *Venice 1993-94 Exhibition Catalogue*, pp. 178-180 (no. 79).

#1099 Astrolabe made by Aḥmad ibn Muḥammad al-Naqqāsh in Saragossa in 472 H [= 1079/80] – Nuremberg, Germanisches Nationalmuseum, inv. no. WI 353 – see *Granada-New York 1992 Exhibition Catalogue*, pp. 376-377 (no. 120); and *Nuremberg GNM 1992-93 Exhibition Catalogue*, II, pp. 568-570 (no. 1.70).

#1148 Astrolabe by al-Khamāʾirī dated 628 H [= 1230/31], with later inscriptions in a dialect of Northern Spain – Cairo, Museum of Islamic Art, inv. no. 15371 – unpublished; see Maier, "Romanische Monatsnamen", A, pp. 247-249.

#2041 Medieval French (?) astrolabe with zoomorphic features on the rete – Oxford, Museum of the History of Science, inv. no. 57-84/173 (Billmeir 173) – unpublished; the front and back are illustrated in Poulle, *Instruments du Moyen Age*, pp. 12 and 14.

#2572 Andalusī astrolabe by Muḥammad al-Sahlī dated 483 H [= 1090/91] with a replacement rete bearing Hebrew inscriptions – Washington, D.C., National Museum of American History, inv. no. 318178 – see

Washington NMAH Catalogue, pp. 174-177 (no. 2752); Goldstein & Saliba, "Hispano-Arabic-Hebrew Astrolabe"; and now a new study, Lacarenza, "Il ragno ebraico dell'astrolabio di Ibn al-Sahlī".

#3042 Astrolabe from 10th-century Catalonia – Paris, Institut du Monde Arabe, inv. no. AI 36-31 – see King, "Earliest European Astrolabe", and other papers in Stevens et al., *Oldest Latin Astrolabe*. A fine illustration of the front is in *Cádiz-Algeciras 1995 Exhibition Catalogue*, p. 187.

#3053 Astrolabe signed by Petrus Raimundus of Aragon, made in Barcelona and dated 1375 – Boston, Mass., Museum of Fine Arts, inv. no. 88.654 – see n. 16 for a description in Catalan, to appear; the front is illustrated in King, "Earliest European Astrolabe", fig. 16.

#3058 14th-century French quatrefoil astrolabe with an additional plate for London and Paris and a later signature "I LOND" – Greenwich, National Maritime Museum, inv. no. A60/NA66-12 – see the forthcoming description by Koenraad van Cleempoel in *Greenwich Astrolabe Catalogue*.

#3595 Astrolabe made in 830 H [= 1426/27] by Muḥammad ibn Jaʿfar al-Kirmānī for Ulugh Beg (his name has been removed from the dedication) – Copenhagen, Davids Samling, inv. no. D 25/1986 – unpublished; see *Copenhagen DS Catalogue*, p. 214, King, "Strumentazione", pp. 161 and 165; and *idem*, *Mecca-Centred World-Maps*, pp. 106-108.

#3622 Unsigned astrolabe from Cordova, dated 446 H [= 1054/55], with later Catalan additions – Cracow, Jagiellonian Museum, inv. no. 4037-35/V – see the detailed description in Maier, "Astrolab aus Córdoba".

#3643 Unsigned, undated Maghribī or Andalusī astrolabe with unusual Ottoman replacement rete – Washington, D.C., National Museum of American History, inv. no. 316753 – see Gunther, *Astrolabes*, I, p. 302 (no. 84A); and *Washington NMAH Catalogue*, pp. 177-179 (no. 3643).

#3650 Mater and plates by Muhammad ibn al-Ṣaffār, dated 417 H [= 1026/27] (the rete is a replacement) – Edinburgh, Royal Scottish Museums, inv. no. T1959-62 – not properly published; see *Instrument Directory*, p. 27, fig. 6 (front only).

#3906 Medieval astrolabe with inscriptions in Hebrew – Paris, private collection – see Bandeira Ferreira, "Astrolábio hebraico", and also Goldstein, "Hebrew Astrolabe".

#3915 Astrolabe with inscriptions in Judaeo-Arabic, al-Andalus or the Maghrib, *ca.* 1300 (?) – London, N. D. Khalili Collection, inv. no. SC 1158 – see *Christie's Amsterdam 15.12.1988 Catalogue*; *Khalili Collection Catalogue*, II, pp. 214-217 (no. 124); and King, "Cataloguing Islamic Instruments", col. 253.

#4024 An illustration of a 10th-century Andalusī astrolabe signed by Khalaf ibn al-Muʿādh, found in a Latin manuscript – MS Paris BN lat. 7412, fols. 19v-23v – see most recently Kunitzsch, "10th-Century Astrolabe", and the bibliography there cited.

#4029 Unsigned astrolabe from 14th-century Yemen – Paris, Institut du Monde Arabe, inv. AI 86-15 – see *Paris IMA Catalogue*, pp. 89-90 (no. 5).

#4036 Astrolabe by Ḥasan ibn ʿUmar al-Naqqāsh, dated 681 H [= 1282/83], with Coptic numerals and silver inlay throughout – Istanbul, Turkish and Islamic Archaeological Museum, inv. no. 2970 – unpublished; the front is illustrated in Nasr, *Islamic Science*, p. 120, pl. 73; the geographical gazetteer is discussed in King, *Mecca-Centred World-Maps*, pp. 76-78 and 600-602.

#4046 Unsigned undated Maghribī astrolabe, datable *ca.* 1600 – Qatar, National Museum – see *Geneva MAH 1985 Exhibition Catalogue*, pp. 284-285 (no. 296), and the more detailed description in *Sotheby's 16.10.1997 Catalogue*, pp. 70-73 (lot 25).

#4182 Astrolabe made in Fez in 719 H [= 1319/20] by Muḥammad ibn Qāsim al-Qurṭubī – in 1971 in the possession of M. Dagron of Paris; present location unknown – unpublished. See here Fig. 12.

#4217 Astrolabe made in Granada in 886 H [= 1481/82] by Muḥammad ibn Zawāl (??) – Granada, Museo Arqueológico Provincial, inv. no. 12115 – see Mendoza Eguaras, "Astrolabio de Granada", and *Madrid 1992 Exhibition Catalogue*, p. 227 (no. 44).

#4506 Italian astrolabe bearing the initials "KP" and dated Urbino, 1462 – Moulins, Musée Départemental, stolen – published in detail in King, "Urbino Astrolabe", pp. 130-132; see also *idem*, "Star-Names on Three Medieval Astrolabes", pp. 323-324.

#4509 Italian astrolabe from *ca.* 1300 with a replacement plate from a Byzantine astrolabe and additional markings in Hebrew – private collection, acquired at Sotheby's of London on 18.6.1986 (lot 125) – see *Amsterdam 1990 Exhibition Catalogue*, p. 101 (no. 186) and p. 106.

#4523 Astrolabe made by Antonius de Pacent in Lanzano in 1420 – Germany, private collection – see the detailed description in Stautz, "Astrolab aus 1420".

#4560 The astrolabe under discussion – private collection – see n. 1.

#4561 A 16th-century Spanish universal astrolabe – formerly private collection, acquired in 1999 by the Museo Nacional de Ciencia y Tecnología, Madrid – see the detailed description in Moreno *et al.*, "Spanish Astrolabe".

Appendix B
The earliest European astrolabes from Spain and France, listed chronologically by region

Note: For lists of the 40-odd earliest Islamic astrolabes and some 35 of the earliest European astrolabes see King, "Earliest European Astrolabe", pp. 387-391.

Catalonia (10th century):

#3042 (the so-called "Carolingian astrolabe")

Uncertain provenance:

#161 (clearly early, Spain?/France?, plates serve the seven climates) – present location unknown!

#420 (12th/13th century?, Spain?/France?, plates serve the seven climates)

#191 (a composite piece, date(s) uncertain, Italian mater, rete entirely Islamic in design, original plates for Saragossa, Toulouse and Paris)

Catalonia (11th-15th century):

#162 (with rectangular frame within rete, *ca.* 1300)

#416 (with Y-shaped frame within rete, *ca.* 1300)

#3053 (signed by Petrus Raimundus, dated Barcelona, 1375)

Central or Northern Spain, excluding Catalonia (12th-15th century):

#4560 (the astrolabe with Latin and Arabic and Hebrew inscriptions described here, probably 14th century)

Southern Spain or the Maghrib (*ca.* 1300 (?)):

#3915 (astrolabe with Judaeo-Arabic inscriptions, with rete design closely related to that on #162, *ca.* 1300)

Southern France:

Ø

Northern France (prior to *ca.* 1400 – selected):

#198 (14th century, with luni-solar gear mechanism)

#202 (14th century, Picardy, featuring monastic numerical ciphers)

#300 (13th/14th century, Northern France and/or Southern England, includes plates which would serve Paris and London)

#428 (*ca.* 1300, lions on throne, "Hispano-mauresque" rete, plates for 14 latitudes between 15° and 48° Paris, including 43° Tolosa, that is, Toulouse)

#2041 (14th century, *fleur-de-lys* design on throne, zoomorphic features on rete, plates for 10 latitudes between 22° and 48° with no localities mentioned, most probably French, although FEBROARIUS suggests Italian influence)

#190 (14th century (?), quatrefoil rete, single astrolabic plate with markings for 48;50°, that is, Paris)

There are some 30 known astrolabes from the workshop of Jean Fusoris in Paris *ca.* 1400 (*e.g.*, #192, #193, #194 in Gunther) or Fusoris-type instruments (including some predating Fusoris), which do not concern us here. The best publication on French astrolabes of this type is Glasemann, "Zwei mittelalterliche französische Astrolabien". Likewise, there are numerous quatrefoil astrolabes that could be French and prior to *ca.* 1400 (such as #3058), but their provenance is not certain.

Notes: Gunther's "Spanish" #161 is a composite piece, and at least the mater is Italian. His "Spanish" #163 is French.

Bibliography and bibliographical abbreviations

Note: Items asterisked were consulted but no relevant materials were found.

Aballagh, "Fractions chez Ibn al-Bannā'": Mohamed Aballagh, "Les fractions entre la théorie et la pratique chez Ibn al-Bannā' al-Marrākushī (1256-1321)", in Benoit *et al.*, eds., *Histoire des fractions*, pp. 247-258.

Aballagh & Djebbar, "Découverte": *idem* and Ahmed Djebbar, "Découverte d'un écrit mathématique d'al-Ḥaṣṣār (XII^e s.): Le livre I du Kāmil", *Historia Mathematica* 14 (1987), pp. 147-158.

.Aguiar Aguilar, *Tratado de Ibn Mas'ūd*: Maravillas Aguiar Aguilar, Risalat Kayfiyat al-sayb fi l-ʿamal bi-l-jayb *de 'Izz al-Din b. Masʿud: Un tratado del siglo XIV acerca de los usos del cuadrante de senos*, unpublished doctoral thesis, Universidad de La Laguna (Tenerife), 1995.

- , "'Abd al-'Azīz ibn Mas'ūd": *eadem*, "En torno a 'Abd al-'Azīz b. Mas'ūd", *Boletín de la Asociación Española de Orientalistas* (Madrid) 32 (1996), pp. 187-196.

- , "Tratado árabe oriental": *eadem*, "Las aplicaciones del cuadrante de senos en agrimensura a través de un tratado árabe oriental del siglo XIV", in C. Álvarez de Morales, ed., *Ciencias de la naturaleza en al-Andalus: Textos y estudios*, IV, Granada: Consejo Superior de Investigaciones Científicas, 1996, pp. 93-113.

Ahmad, "Arabic Chronograms": Qeyamuddin Ahmad, "A Note on the Art of Composing Chronograms", *Islamic Culture* 46 (1972), pp. 163-169.

Algeciras-Cádiz 1995 Exhibition Catalogue: see *Cádiz-Algeciras* ... .

Allard, "Fractions dans les premières arithmétiques latines": André Allard, "Le traitement des fractions dans les premiers textes latins du XII^e siècle influencés par l'arithmétique arabe", in Benoit *et al.*, eds., *Histoire des fractions*, pp. 290-302

Amsterdam 1990 Exhibition Catalogue: Anthony J. Turner, ed., *Time*, The Hague: Tijd voor Tijd Foundation, 1990. [A catalogue of an exhibition held at the 'Nieuwe Kerk', Amsterdam, from Nov., 1990 to Jan., 1991.]

Arnall i Juan & Pons i Guri, *L'Escriptura a les terres gironines*: M. Josepa Arnall i Juan and Josep M. Pons i Guri, *L'Escriptura a les terres gironines segles IX-XVIII*, Girona: Diputació de Girona, 1993.

Arribas Arranz, *Paleografia hispanica*: Filemón Arribas Arranz, *Paleografia documental hispanica*, 2 vols., Valladolid: Sever-Cuesta, 1965.

Ars Hispaniae: *Ars Hispaniae – Historia universal del arte hispánico*, 22 vols., Madrid: Plus-Ultra, 1947-1977, especially vol. III: *El Arte árabe español hasta los Almohades*, by Manuel Gómez-Moreno, 1951; vol. IV: *Arte Almohade – Arte Nazarí – Arte mudéjar*, by Leopoldo Torres Balbas, 1949; vol. VII: *Arquitectura gótica*, by *idem*, 1952; vol. VIII: *Escultura gótica*, by Agustín Durán Sanpere and Juan Ainaud de Lasarte, 1956; and vol. IX: *Pintura gótica*, by José Gudiol Ricart, 1955.

Atıl, *Mamluk Art*: Esin Atıl, *Renaissance of Islam: Art of the Mamluks*, Washington, D.C.: Smithsonian Institution Press, 1981.

Bandeira Ferreira, "Astrolábio hebraico": "Descrição sumaria de um astrolábio planisférico com legendas em caracteres hebraicos", *Revista da Faculdade de Letras, Universidade de Lisboa*, 3rd. series, no. 8 (1964), pp. 168-178.

Barral i Altet: see *Rennes 1983 Conference Proceedings*.

Beaujouan, "Chiffres arabes": Guy Beaujouan, "Les chiffres arabes selon Gerbert: l'abaque du Pseudo-Boèce - XIe siècle", in Olivier Guyot-jeannin and Emmanuel Poulle, eds., *Autour de Gerbert d'Aurillac, le pape de l'an mil*, Paris: École des Chartes, 1996.

- , "Rotation des chiffres": *idem*, "Étude paléographique sur la rotation des chiffres et l'emploi des apices du X^e au XII^e siècle", *Revue d'Histoire des Sciences* 1 (1947), pp. 301-311, repr. in *idem*, *Studies*, A-IX.

- , *Studies*, A-B: *idem*, *Par raison de nombres – L'art du calcul et les savoirs scientifiques médiévaux* (A), and *Science médiévale d'Espagne et d'alentour* (B), Aldershot: Variorum, 1990 and 1992.

Behrens-Abouseif, "Baptistère de Saint Louis": Doris Behrens-Abouseif, "The Baptistère de Saint Louis: A Reinterpretation", *Islamic Art* 3 (1988/89), pp. 3-13 and pls. I-II.

Benoit, "Arithmétiques commerciales françaises": Paul Benoit, "Arithmétiques commerciales et comptabilités dans la France médiévale", in Benoit *et al.*, eds., *Histoire des fractions*, pp. 306-323.

Benoit *et al.*, eds., *Histoire des fractions*: P. Benoit, K. Chemla and J. Ritter, eds., *Histoire des fractions: Fractions d'histoire*, Basle: Birkhäuser, 1992.

Berggren, "Drawing Azimuth Circles": J. Lennart Berggren, "Medieval Islamic Methods for Drawing Azimuth Circles on the Astrolabe", *Centaurus* 34 (1991), pp. 309-344.

- , *Episodes*: *idem*, *Episodes in the Mathematics of Medieval Islam*, New York, N.Y., *etc.*: Springer, 1986.

Berlin MGB 1989 Exhibition Catalogue: Gereon Sievernich and Hendrik Budde, *Europa und der Orient 800-1900*, Gütersloh & Munich: Bertelsmann, 1989. [Catalogue of an exhibition at the Martin-Gropius-Bau, Berlin, during 28.5.-17.8.1989.]

Berlin MIK 1981 Exhibition Catalogue: Richard Ettinghausen *et al.*, *The Arts of Islam: Masterpieces from The Metropolitan Museum of Art, New York*, Berlin: Staatliche Museen, Preußischer Kultur Besitz, 1981. [Catalogue of an exhibition at the Museum für Islamische Kunst during 20.6.-23.8.1981.]

Birnbaum, *Hebrew Scripts*: Solomon A. Birnbaum, *The Hebrew Scripts*, 2 vols., Leiden: E. J. Brill, 1954-71.

Bischoff, *Paläographie, etc.*: Bernhard Bischoff, *Paläographie des römischen Altertums und des abendländischen Mittelalters*, (first published 1956), Berlin, Bielefeld & Munich: Erich Schmidt, 1979, translated into French as *Paléographie de l'antiquité romaine et du moyen âge occidental*, Paris: Picard, 1985, and into English as *Latin Palaeography – Antiquity and the Middle Ages*, Cambridge, *etc.*: Cambridge University Press, 1990.

Boswell, *Muslims in 14th-Century Aragon*: John Boswell, *The Royal Treasure: Muslim Communities under the Crown of Aragon in the Fourteenth Century*, New Haven, Conn., & London: Yale University Press, 1977.

Bosworth, *Islamic Dynasties*: Clifford Edmund Bosworth, *The Islamic Dynasties – A Chronological and Genealogical Handbook*, Edinburgh: Edinburgh University Press, 1967, enlarged and updated edn. published as *The New Islamic Dynasties ...* , New York, N.Y.: Columbia University Press, 1996.

Brockelmann, *GAL*: Carl Brockelmann, *Geschichte der arabischen Litteratur*, 2nd edn., 2 vols., Leiden: E. J. Brill, 1943-49, and Supplementbände: 3 vols., Leiden: E. J. Brill, 1937-42.

Brown, *Historical Scripts*: Michelle P. Brown, *A Guide to Western Historical Scripts from Antiquity to 1600*, London: The British Library, 1990.

Brussels SG 1984 Exhibition Catalogue: Georges Baptiste *et al.*, *La mesure du temps dans les collections belges*, Brussels: Société Générale de Banque, 1984. [Catalogue of an exhibition held at the Bank in Brussels during 26.1.-7.4.1984.]

Burnett, "Abacus at Echternach": Charles Burnett, "The Abacus at Echternach in *ca.* 1000 A.D.", *SCIAMVS – Sources and Commentaries in Exact Sciences* (Kyoto, Hokuto) 3 (2002), pp. 91-108.

- , *Studies*: *idem*, *Magic and Divination in the Middle Ages – Texts and Techniques in the Islamic and Christian Worlds*, Aldershot: Variorum, 1996.

Buzineb, "Respuestas": Hossein Buzineb, "Respuestas de jurisconsultos maghribíes en torno a la immigración de musulmanes hispánicos", *Hespéris Tamuda* 26-27 (1988-89), pp. 53-66.

Cádiz-Algeciras 1995 Exhibition Catalogue: *Al-Andalus y el Mediterráneo*, Barcelona & Madrid: Lunwerg Editores S.A., 1995. [Catalogue of an exhibition held in the Museo Arqueológico Provincial de Cádiz and the Casa de la Cultura de Algeciras in 1995.]

Cairo ENL Survey: David A. King, *A Survey of the Scientific Manuscripts in the Egyptian National Library*, (Publications of the American Research Center in Egypt, Catalogs, vol. 5), Winona Lake, Ind.: Eisenbrauns, 1986.

Cajori, *Mathematical Notations*: Florian Cajori, *A History of Mathematical Notations*, 2 vols., Chicago, Ill.: The Open Court Publishing Company, 1928-29, repr. La Salle, Ill.: The Open Court Publishing Company, 1951-52.

Cambridge DI 1998 Conference Proceedings: Jed Buchwald, gen. ed., *New Perspectives on Science in Medieval Islam*, Cambridge, Mass.: Massachusetts Institute of Technology Press, 1999. [Proceedings of a conference held at the Dibner Institute during 6-8.11.1998.]

Cappelli, *Lexicon abbreviaturarum*: Adriano Cappelli, *Lexicon abbreviaturarum – Dizionario di abbreviature latine ed italiane*, Milan: Ulrico Hoepli, 1990 (reprint of the 6th edition, 1961). [The German version is available with the title *Lexicon abbreviaturarum – Wörterbuch lateinischer und italienischer Abkürzungen*, 2nd improved edn., Leipzig: J. J. Weber, 1928.]

Carboni: see *New York MMA 1997 Exhibition Catalogue*.

Castro, *Glosarios latino-españoles*: Américo Castro, *Glosarios latino-españoles de la edad media, Revista de filología española* (Madrid) 22 (1936).

Cátedra & Samsó, *Astrología de Enrique de Villena*: Pedro M. Cátedra and Julio Samsó, *Tratado de astrología atribuido a Enrique de Villena*, Madrid: Río Tinto Minera, 1980.

Chabàs & Roca, *Lunari de Bernat de Granollachs*: Josep Chabàs and Antoni Roca, *El "Lunari" de Bernat de Granollachs – alguns aspectes de la història de l'astronomia a la Catalunya del Quatre-cents*, Barcelona: Fundació Salvador Vives i Casajuana, 1985.

Chassant, *Dictionnaire des abréviations*: L. Alphonse Chassant, *Dictionnaire des abréviations latines et françaises usitées dans les inscriptions lapidaires et métalliques les manuscrits et les chartes du Moyen Âge*, 5th edn., Paris, 1884, repr. Hildesheim: Georg Olms, 1965.

Chemla, "Fractions en Chine": Karine Chemla, "Les fractions comme modèle formel en Chine ancienne", in Benoit *et al.*, eds., *Histoire des fractions*, pp. 189-207,

Cherbonneau, "Voyage d'El-Abdéry", A-B: Auguste Cherbonneau, "Notice et extraits du voyage d'El-Abdery à travers l'Afrique septentrionale, au VII^e^ siècle de l'Hégire", *Journal asiatique* (Paris), 5^e^ série, 4 (1854), pp. 144-176, and "Voyage d'El-Abdéry à travers l'Afrique septentrionale au treizième siècle", *Revue de Géographie* (Paris), 4^e^ année, tome 7 (1880), pp. 50-61, repr. in *Islamic Geography*, vol. 174 (1994), pp. 1-33 and 34-45.

Chicago AP Catalogue, I-II: Bruce Chandler with Sara Schechter Genuth, eds., *Historic Scientific Instruments of the Adler Planetarium & Astronomy Museum*, vol. I: *Western Astrolabes*, by Roderick and

Marjorie Webster, Chicago, Ill.: Adler Planetarium & Astronomy Museum, 1998, and vol. II: *Eastern Astrolabes*, in press.

Christie's Amsterdam 15.12.1988 Catalogue: *Christie's Amsterdam, Important Judaica, Thursday, 15 December, 1988*, Amsterdam: Christie's, 1988.

Christie's London 15.4.1999 Catalogue: *Exceptional Scientific and Engineering Works of Art, Instruments and Models, Thursday, 15 April 1999*, London: Christie's South Kensington, 1999.

* Cooper, "Language of Late Medieval Aragon": Louis Cooper, "On the Language of Upper Aragon (1258-1495): A Review Article", *Hispanic Review* (New York) 28 (1960), pp. 262-275. [A linguistic review of T. Navarro Tomás, *Documentos lingüísticos del Alto Aragon*, Syracuse, N.Y.: Syracuse University Press, 1957.]

Colin, "Charte hispano-arabe": G. S. Colin, "Sur une charte hispano-arabe de 1312", *Islamica* (Leipzig) 3 (1927), pp. 363-390.

Copenhagen DS Catalogue: Kjeld von Folsach, *Islamic Art – The David Collection*, Copenhagen: Davids Samling, 1990.

Corominas, *Diccionario*: Joan Corominas, with assistance from José A. Pascual, *Diccionario crítico etimológico castellano e hispánico*, revised from the 1954 edn., 5 vols., Madrid: Gredos, 1983.

Corriente, *Dictionary of Andalusi Arabic*: Federico Corriente, *A Dictionary of Andalusi Arabic*, (*Handbuch der Orientalistik*, Band I:29), Leiden, New York, N.Y., & Cologne: E. J. Brill, 1997.

- , *Spanish Arabic*: *idem*, *A Grammatical Sketch of the Spanish-Arabic Dialect Bundle*, Madrid: Instituto Hispano-Árabe de Cultura, 1977.

Costamagna *et al.*, *Notæ Tironianæ*: Giorgio Costamagna, Maria Franca Baroni and Luisa Zagni, *Notæ Tironianæ quæ in lexicis et in chartis reperiuntur novo discrimine ordinatæ*, (*Fonti e studi del Corpus membranarum italicarum*, 2ª serie, X), Rome: Il Centro di Ricerca, 1983.

Culver, "Early European Instruments": H. B. Culver, "Early Mathematical Instruments of Europe", *International Studio: Associated with the Connoisseur*, December 1928, pp. 34-36.

Dekker: see Kunitzsch & Dekker and G. Turner & Dekker.

Delgràs, *Historia de la escritura*: Leopoldo Delgràs, *Historia de la escritura dedicada al Excmo. Sr. D. José de Salamanca*, 1865. [A handprinted folio – MS Madrid BN 18714(65).]

Delisle & Traube, "Signe abréviatif": L. Delisle and L. Traube, "De l'emploi du signe abréviatif 9 à la fin des mots", *Bibliothèque de l'Ecole des Chartes* 67 (1906), pp. 591-592. [See also Poupardin, "Abréviation".]

Destombes, "Astrolabe carolingien": Marcel Destombes, "Un astrolabe carolingien et l'origine de nos chiffres arabes", *Archives Internationales d'Histoire des Sciences* 58-59 (1962), pp. 1-45, repr. in G. Schilder, P. van der Krogt, S. de Clercq, eds., *M. Destombes (1905-1983): Selected Contributions to the History of Cartography and Scientific Instruments*, Utrecht: Hes, & Paris: A. G. Nizet, 1987, pp. 153-200.

Dict. arch. chrét.: Fernand Cabrol and Henri Leclercq, *Dictionnaire d'archéologie chrétienne et de liturgie*, 15 pts. in 30 vols., Paris: Letouzey et Ané, 1913-53.

Djebbar, *Études*: Ahmed Djebbar, *Mathématiques et mathématiciens dans le Maghreb mediéval (IXe-XVIe s.) – Contribution à l'étude des activités scientifiques de l'Occident musulman*, 2 vols., Paris, 1998. [Contains reprints of various studies published between 1980 and 1990, privately distributed.]

- , "Fractions au Maghreb": *idem*, "Le traitement des fractions dans la tradition mathématique arabe au Maghreb", in Benoit *et al.*, eds., *Histoire des fractions*, pp. 223-245,

DMA: Joseph R. Strayer, ed., *Dictionary of the Middle Ages*, 13 vols., New York, N.Y.: Charles Scribner's Sons, 1982-89. Especially articles "Arabic Numerals"; "Paleography"; and "Roman Numerals".

DSB: *Dictionary of Scientific Biography*, 16 vols., New York, N.Y.: Charles Scribner's Sons, 1970-80.

EHAS / HSA: Roshdi Rashed, with Régis Morelon, eds., *Encyclopedia of the History of Arabic Science*, 3 vols., London: Routledge, 1996; with French translation *Histoire de la science arabe*, Paris: Seuil, 1997.

EI_2: *Encyclopaedia of Islam*, new edn., 11 vols. to date, Leiden: E. J. Brill, 1960 to present. Especially articles "Algeria, ii.1" [= history of Algeria to the 16th century]; "Al-Andalus" [= "Muslim Spain"]; "Arabesque"

[= "denaturalized vegetal ornament"]; "'Arūḍ" [= poetic metres]; "al-Asmā' al-ḥusnā" [= the 99 names of God]; "Asṭurlāb" [= astrolabe]; "Bīdjāya" [= Bougie]; "Budūḥ" [= talismans]; "al-Djazā'ir" [= Algiers]; "Ḥafṣids" [= Tunisian dynasty]; "Ḥurūf, 'Ilm al-" [= letter-magic]; "Judaeo-Arabic" [= Arabic written in Hebrew characters]; "Khaṭṭ" [= script]; "al-Maghrib" [= the entire Maghrib]; "Malik" [= king, also a name of God]; "al-Mālikiyya" [= the Mālikī legal school]; "al-Marrākushī" [= Moroccan astronomer active in Cairo in the late 13th century]; "Mīḳāt" [= astronomical timekeeping and the regulation of the times of prayer]; "Mu'ammā" [= coded script"]; "Mudéjar" [= Muslims living under Christian domination in Spain]; "al-Naṣāra" [= Christians in the Islamic East]; "Naṣrids" [= last Muslim dynasty in Spain (Kingdom of Granada)]; "Rub'" [= quadrant]; "Saraḳusṭa" [= Saragossa]; "Shafaḳ" [= twilight]; "Ṭulayṭula" [= Toledo]; "Tūnis" [= Tunis]; and "Zīdj" [= astronomical handbooks, astronomical tables, and mathematical astronomy in general].

EJ: *Encyclopaedia Judaica*, 16 vols., Jerusalem: Keter, 1971-72, with later supplements and indexes. Especially articles "Algiers"; "Metals and Mining"; "Saragossa"; and "Toledo".

Eneström, "Bezeichnung von Brüchen": Gustaf Eneström, "Über die Bezeichnung gewöhnlicher Brüche im christlichen Mittelalter nach der Einführung arabischer Ziffern", *Bibliotheca Mathematica – Zeitschrift für Geschichte der mathematischen Wissenschaften*, 3. Folge, 7 (1906/07), pp. 308-309.

Escorial Catalogue A: M. Casiri, *Bibliotheca Arabico-Hispana Escurialensis*, Madrid, 1760-70.

Escorial Catalogue B: H. J. P. Renaud, *Les manuscrits arabes de l'Escorial*, tome II, fasc. 3: *Sciences exactes et sciences occultes*, Paris: Paul Geuthner, 1941.

Escultura en Andalucia: *La escultura en Andalucia*, 3 vols., Seville: Universidad de Sevilla, Facultad de Filosofía y Letras, n.d. [*ca*. 1930?]

Fagnan, "Tabakāt malekites": E. Fagnan, "Les tabakāt malekites", in *Homenaje á D. Francisco Codera en su jubilación del profesorado*, (with an introduction by Eduardo Saavedra), Saragossa: Mariano Escar, 1904, pp. 105-113.

Fahd, *Divination arabe*: Toufic Fahd, *La divination arabe*, (thesis at the Université de Strasbourg, 1966), Paris: Sindbad, 1987.

Fernández-Puertas, "Calligraphy in Al-Andalus": Antonio Fernández-Puertas, "Calligraphy in Al-Andalus", in Jayyusi, ed., *Muslim Spain*, II, pp. 639-676.

Folkerts & Kunitzsch, *al-Khwārizmī*: Menso Folkerts with Paul Kunitzsch, *Die älteste lateinische Schrift über das indische Rechnen nach al-Ḫwārizmī, Abhandlungen der Philosophisch-Historischen Klasse der Bayerischen Akademie der Wissenschaften*, N. F., Heft 113, Munich, 1997.

Frankfurt IGN Festband: Anton von Gotstedter, ed., *Ad radices – Festband zum fünfzigjährigen Bestehen des Instituts für Geschichte der Naturwissenschaften Frankfurt am Main*, Stuttgart: Franz Steiner, 1994.

Friedenberg, "Spanish Jewish Seals": Daniel M. Friedenberg, "A Bonanza of Spanish Jewish Pre-Expulsion Seals", in *Sepharad*, pp. 100-108.

Gabrieli, ed., *L'Islam en Europe*: Francesco Gabrieli, ed., *Histoire et civilisation de l'Islam en Europe*, (translated under the direction of Jean-Paul Roux from the 1982 Italian original *Maometto in Europa*), Paris: Bordas, 1983.

Gandz, "Hebrew Numerals": Solomon Gandz, "Hebrew Numerals", *American Academy for Jewish Research* 4 (1932-33), pp. 53-112.

García Franco, *Astrolabios en España*: Salvador García Franco, *Catálogo crítico de los astrolabios existentes en España*, Madrid: Instituto Histórico de la Marina, 1945.

García Villada, *Paleografía española*: Zacarías García Villada, *Paleografía española*, 2 vols., Madrid: Junta para ampliacion de estudios e investigaciones científicas, 1923.

Geneva MAH 1985 Exhibition Catalogue: Toby Falk, ed., *Treasures of Islam*, London: Sotheby's and Philip Wilson, 1985. [Catalogue of an exhibition at the Musée d'art et d'histoire, Geneva, in 1985.]

Gimeno Blay, "Escrituras bajomedievales": Francisco M. Gimeno Blay, "Materiales para el estudio de las escrituras de aparato bajomedievales – la collección epigráfica de Valencia", in Walter Koch, ed., *Epigraphik 1988 – Fachtagung für mitterlalterliche und neuzeitliche Epigraphik, Graz, 10.-14. Mai 1988, Referate und Round-Table-Ge-*

spräche, (ÖAK, Phil.-hist. Kl., Denkschriften, 213. Band), Vienna: Österreichische Akademie der Wissenschaften, 1990, pp. 195-216.

Glasemann, "Zwei mittelalterliche französische Astrolabien", Reinhard Glasemann, "Zwei mittelalterliche französische Astrolabien", in *Frankfurt IGN Festband*, pp. 211-230.

Glick, *Islamic and Christian Spain*: Thomas F. Glick, *Islamic and Christian Spain in the Early Middle Ages*, Princeton, N.J.: Princeton University Press, 1979.

- , "Jewish Contribution to Science in Medieval Spain": *idem*, "Science in Medieval Spain: The Jewish Contribution in the Context of *Convivencia*", in *New York JM 1992 Exhibition Catalogue*, pp. 82-111.

Goldstein, "Arabic Science in Hebrew": Bernard R. Goldstein, "The Heritage of Arabic Science in Hebrew", in *EHAS*, I, pp. 276-283.

- , "Astronomy of Spanish Jews": *idem*, "Astronomy in the Medieval Spanish Jewish Community", in *North Festschrift*, pp. 225-241.

- , "Hebrew Astrolabe": *idem*, "The Hebrew Astrolabe in the Adler Planetarium", *Journal of Near Eastern Studies* 35 (1976), pp. 251-260, repr. in *idem*, *Studies*, XVIII.

- , "Hebrew Instrument Descriptions": *idem*, "Descriptions of Astronomical Instruments in Hebrew", in *Kennedy Festschrift*, pp. 105-141.

- , "Role of Science": *idem*, "The Role of Science in the Jewish Community in Fourteenth-Century France", *Annals of the New York Academy of Science* 314 (1978), pp. 39-49, repr. in *idem*, *Studies*, XX.

- , *Studies*: *idem*, *Theory and Observation in Ancient and Medieval Astronomy*, London: Variorum, 1985.

Goldstein & Saliba, "Hispano-Arabic-Hebrew Astrolabe": *idem* and George Saliba, "A Hispano-Arabic Astrolabe with Hebrew Star Names", *Annali dell'Istituto e Museo di Storia della Scienza di Firenze* 8 (1983), pp. 19-28, repr. in *idem*, *Studies*, XIX.

Granada-New York 1992 Exhibition Catalogue: Jerrilynn D. Dodds, ed., *Al-Andalus – The Art of Islamic Spain*, New York, N.Y.: The Metropolitan Museum of Art, 1992. [Catalogue of an exhibition held at the Alhambra, Granada during 18.3.-7.6.1992 and at The Metropolitan Museum of Art during 1.7.-27.9.1992.]

Gratuze & Barrandon, "Nouvelles analyses": B. Gratuze and J.-N. Barrandon, "Nouvelles analyses de l'astrolabe latin AI. 86-31", in Stevens *et al.*, eds. *Oldest Latin Astrolabe*, pp. 433-438.

Greenwich Astrolabe Catalogue: A catalogue of the astrolabes in the National Maritime Museum at Greenwich, edited by Koenraad van Cleempoel, to be published by Oxford University Press.

Greenwich NMM Handlist: *The Planispheric Astrolabe*, Greenwich: National Maritime Museum, 1976, repr. several times.

Gunther, *Astrolabes*: Robert T. Gunther, *The Astrolabes of the World* ... , 2 vols., Oxford: University Press, 1932, repr. in 1 vol., London: The Holland Press, 1976.

- , *Early Science in Oxford*, II: *idem*, *Early Science in Oxford*, vol. II: Astronomy, Oxford: Clarendon Press, 1923.

Hartner, "Astrolabe", A-B: Willy Hartner, "The Principle and Use of the Astrolabe" (A), a chapter in Pope, ed., *Survey of Persian Art*, repr. without the original plates in Hartner, *Oriens-Occidens*, I, pp. 287-311, and again with them in *Astrolabica* (Paris: Société Internationale de l'Astrolabe), 1 (1978); and *idem*, article "Asṭurlāb" (B) in EI_2, repr. in *idem*, *Oriens-Occidens*, (I), pp. 312-318.

- , *Oriens-Occidens*, I-II: *Willy Hartner – Oriens-Occidens – Ausgewählte Schriften zur Wissenschafts- und Kulturgeschichte – Festschrift zum 60. Geburtstag*, Hildesheim: Georg Olms, 1968 (I); and Yasukatsu Maeyama, ed., *Oriens-Occidens – Ausgewählte Schriften zur Wissenschafts- und Kulturgeschichte – Band II*, Hildesheim, *etc.*: Georg Olms, 1984 (II).

Harvey, *Islamic Spain*: Leonard Patrick Harvey, *Islamic Spain 1250-1500*, Chicago, Ill., & London: The University of Chicago Press, 1990.

- , "The *Mudéjars*": *idem*, "The *Mudéjars*", in Jayyusi, ed., *Muslim Spain*, pp. 176-187.

Hellmann, "Review of King, *Ciphers of the Monks*": Martin Hellmann, "Neue kurzschriftgeschichtliche Erkenntnisse im Zusammenhang mit den 'griechischen' und 'chaldäischen' Zahlzeichen", published in *Archiv für Stenograpfie, Textverarbeitung, Bürotechnik* (Forschungs- und Ausbildungsstätte für Kurzschrift und Textverarbeitung, Bayreuth) in 2002, with a longer version at www.forschungsstaette.de/Rezensionen /King_ 2001.htm.

Hill, *Arabic Numerals*: George Francis Hill, *The Development of Arabic Numerals in Europe Exhibited in Sixty-Four Tables*, Oxford: Clarendon Press, 1915.

* *Hispanica Judaica*: *Hispanica Judaica – Studies on the History, Language and Literature of the Jews in the Hispanic World*, 3 vols. to date, n.d.

Hogendijk, "al-Mu'taman ibn Hūd": Jan P. Hogendijk, "al-Mu'taman ibn Hūd. 11th Century King of Saragossa and Brilliant Mathematician", *Historia Mathematica* 22 (1995), pp. 1-18.

Holbrook: see *Instrument Directory*.

Howse, "Early Tidal Diagrams": H. Derek Howse, "Some Early Tidal Diagrams", *Revista da Universidade de Coimbra* 32 (1986), pp. 365-385.

Ifrah, *Histoire des chiffres*: Georges Ifrah, *Histoire universelle des chiffres*, 2nd edn., Paris: Robert Laffont, 1994. [The first edition is available in English as *From One to Zero – A Universal History of Numbers*, New York, N.Y., *etc*.: Penguin Books, 1988.]

Instrument Directory: Mary Holbrook, *Science Preserved: A directory of scientific instruments in the United Kingdom and Eire*, London: Her Majesty's Stationery Office, 1992.

Irani, "Arabic Numeral Forms": R. A. K. Irani, "Arabic Numeral Forms", *Centaurus* 4 (1955), pp. 1-12, repr. in Kennedy *et al*., *Studies*, pp. 710-721.

Islamic Geography: Fuat Sezgin, with Mazen Amawi, Carl Ehrig-Eggert and Eckhard Neubauer *et al*., eds., *Islamic Geography*, Frankfurt am Main: Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 276 vols. to date, 1992-1998. [Facsimile reprints of early writings, mainly 19th and early-20th century.]

Jami, "Chinese and Western Arithmetics in the 17th Century": Catherine Jami, "The Meeting betweeen Chinese and Western Arithmetics in the Seventeenth Century", in Benoit *et al*., eds., *Histoire des fractions*, pp. 351-373.

Jayyusi, ed., *Muslim Spain*: Salma Khadra Jayyusi, ed., *The Legacy of Muslim Spain*, 2 vols., Leiden, *etc*.: E. J. Brill, 1994. [First published as *Handbuch der Orientalistik*, Band I:12, 1992.]

Jewish Art: see *Sepharad*, a special issue published in 1992.

Juschkewitsch, *Mathematik im Mittelalter*: Adolf P. Juschkewitsch, *Geschichte der Mathematik im Mittelalter*, Leipzig: B. G. Teubner, 1964.

Kedourie, ed., *Spain and the Jews*: Elie Kedourie, ed., *Spain and the Jews – The Sephardi Experience – 1492 and After*, London: Thames & Hudson, 1992.

Kennedy *et al.*, *Studies*: E. S. Kennedy, Colleagues and Former Students, *Studies in the Islamic Exact Sciences*, ed. by Mary Helen Kennedy and David A. King, Beirut: American University of Beirut, 1983.

Kennedy Festschrift: David A. King and George Saliba, eds., *From Deferent to Equant – A Volume of Studies in the History of Science in the Ancient and Medieval Near East in Honor of E. S. Kennedy*, *Annals of the New York Academy of Sciences* 500 (1987).

Kennedy & Kennedy, *Islamic Geographical Coordinates*: E. S. Kennedy and Mary Helen Kennedy, *Geographical Coordinates of Localities from Islamic Sources*, Frankfurt am Main: Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 1987.

Khalili Collection Catalogue: *The Nasser D. Khalili Collection of Islamic Art*, vol. XII: *Science, Tools and Magic*, by Francis Maddison and Emilie Savage-Smith, 2 pts., London: The Nour Foundation, in association with Azimuth Editions and Oxford University Press, 1997. [See also King, "Cataloguing Islamic Instruments".]

King, "Astrolabe of the Yemeni Sultan al-Ashraf": David A. King, "The Medieval Yemeni Astrolabe in the Metropolitan Museum of Art in New York", *ZGAIW* 2 (1985), pp. 99-122, and *ibid.*, 4 (1987/88), pp. 268-269, repr. in *idem*, *Studies*, B-II.

- , "Astronomical Instruments between East and West": *idem*, "Astronomical Instruments between East and West", in *Krems 1992 Conference Proceedings*, pp. 143-198.

- , "Astronomy in the Maghrib": *idem*, "On the History of Astronomy in the Medieval Maghrib", in *Études Philosophiques et Sociologiques Dédiées à Jamal ed-Dine Alaoui*, Université Sidi Mohamed Ben Abdallah, Publications de la Faculté des Lettres et des Sciences Humaines Dhar El Mahraz - Fès, N° Spécial 14 (Département de Philosophie, Sociologie et Psychologie), Fez, 1998 [published 1999], pp. 27-61.

- , “Cataloguing Islamic Instruments”: *idem*, “Cataloguing Islamic Astronomical Instruments”, in *Bibliotheca Orientalis* 57 (2000), cols. 247-258. [An essay review of *Khalili Collection Catalogue*.]
- , *Ciphers of the Monks*: *idem*, *The Ciphers of the Monks – A Forgotten Number Notation of the Middle Ages*, (*Boethius: Texte und Abhandlungen zur Geschichte der Mathematik und der Naturwissenschaften*, Band 44), Stuttgart: Franz Steiner, 2001.
- , “Earliest European Astrolabe”: *idem*, “The Earliest Known European Astrolabe in the Light of Other Early Astrolabes”, in Stevens *et al.*, eds., *The Oldest Latin Astrolabe*, pp. 359-404.
- , “Geography of Early Astrolabes”: *idem*, “Bringing Astronomical Instruments back to Earth: The Geographical Data on Early Astrolabes (to *ca.* 1100)”, in *North Festschrift*, pp. 3-53.
- , “Instrument Catalogue”: *idem*, “Medieval Astronomical Instruments: A Catalogue in Preparation”, *Bulletin of the Scientific Instrument Society* (London) 31 (Dec., 1991), 3-7, also *ibid.*, 36 (March, 1993), pp. 17-18, and 44 (March, 1995), pp. 5-12.
- , “Kuwait Astrolabes”: *idem*, “Early Islamic Astronomical Instruments in Kuwaiti Collections”, in Arlene Fullerton and Géza Fehérvári, eds., *Kuwait – Arts and Architecture – A Collection of Essays*, Kuwait (no publisher named), 1995, pp. 76-96.
- , “Mamluk Astronomy”: *idem*, “The Astronomy of the Mamluks”, *Isis* 74 (1983), pp. 531-555, repr. in *idem*, *Studies*, A-III.
- , *Mecca-Centred World-Maps*: *idem*, *World-Maps for Finding the Direction and Distance to Mecca: Innovation and Tradition in Islamic Science*, Leiden: E. J. Brill, and London: Al-Furqan Islamic Heritage Foundation, 1999.
- , “Medieval Italian Non-Standard Astrolabe”: *idem*, “A Remarkable Italian Astrolabe from *ca.* 1300 – Witness to an Ingenious Tradition of Non-Standard Astrolabes”, to appear in a *Festschrift* for Mara Miniati, Florence, in a special issue of *Nuncius*.
- , “The Neglected Astrolabe”: *idem*, “The Neglected Astrolabe”, in Menso Folkerts, ed., *Mathematische Probleme im Mittelalter – Der lateinische und arabische Sprachbereich*, (Wolfenbütteler Mittelalter-Studien, Band 10), Wiesbaden: Otto Harrassowitz, for the Herzog August-Bibliothek, Wolfenbüttel, 1996, pp. 45-55.

- , *SATMI*: *idem*, *Studies in Astronomical Timekeeping in Medieval Islam*, 12 pts., Leiden: E. J. Brill, in press.
- , "Star-Names on Three European Astrolabes": *idem*, "The Stars-Names on Three 14th-Century Astrolabes from Spain, France and Italy", in *Kunitzsch Festschrift*, pp. 307-333.
- , "Strumentazione": *idem*, "Strumentazione astronomica nel mondo medievale Islamico", in Gerard L'E. Turner, ed., *Gli strumenti*, 2nd edn., Turin: Giulio Einaudi, 1991, pp. 154-189 and pp. 581-585 (bibliography). [An updated version of the original Englsih is to appear as *SATMI*, VIII.]
- , *Studies*, A-C: *idem*, *Islamic Mathematical Astronomy*, London: Variorum, 1986, 2nd rev. edn., Aldershot: Variorum, 1993 (A); *Islamic Astronomical Instruments*, London: Variorum, 1987, repr. Aldershot: Variorum, 1995 (B); and *Astronomy in the Service of Islam*, Aldershot: Variorum, 1993 (C).
- , "Urbino Astrolabe": *idem*, "The Astrolabe Depicted in the Intarsia of the *Studiolo* of Archduke Federico in Urbino", in *La scienza del Ducato di Urbino – The Science of the Dukedom of Urbino*, Flavio Vetrano, ed., Urbino: Accademia Raffaello, 2001, pp. 101-139.

King & Maier, "Catalan Astrolabe": *idem* and Kurt Maier, "The Medieval Catalan Astrolabe in the Society of Antiquaries, London", in *Vernet Festschrift*, II, pp. 673-718.

King & G. Turner, "Bessarion's Astrolabe": *idem* and Gerard L'E. Turner, "The Astrolabe Presented by Regiomontanus to Cardinal Bessarion in 1462", *Nuncius – Annali di Storia della Scienza* (Florence) 9 (1994), pp. 165-206, repr. in Turner, *Studies*.

Kisch, *Scales and Weights*: Bruno Kisch, *Scales and Weights – A Historical Outline*, New Haven, Ct., & London: Yale University Press, 1965, repr. 1966.

van Koningsveld, "Arabic Manuscripts from Christian Spain", A-B: Peter Sjord van Koningsveld, "Andalusian Arabic Manuscripts from Christian Spain – A Comparative Intercultural Approach", *Israel Oriental Studies* (E. J. Brill, Leiden) 12 (1992), pp. 75-110 (A); and "Andalusian Arabic Manuscripts from Medieval Christian Spain – Some Supplementary Notes", in *Festgabe für Hans-Rudolf Singer zum 65. Geburtstag am 16. April 1990 überreicht von seinen Freunden und*

Kollegen, 2 vols., Frankfurt am Main: Peter Lang, 1991 [published 1993], II, pp. 811-823 (B).

- , "Christian Arabic Literature from Medieval Spain": *idem*, "Christian Arabic Literature from Medieval Spain – An Attempt at Periodization", in S. K. Samir and J. S. Nielsen, eds., *Christian Arabic Apologetics during the Abbassid Period (750-1258)*, Leiden: E. J. Brill, 1994, pp. 203-224.

- , "Muslim Captives": *idem*, "Muslim Slaves and Captives in Western Europe during the Late Middle Ages", *Islamic and Christian-Muslim Relations* 6 (1995), pp. 5-23.

- & Wiegers, "Polemics of al-Qaysī": *idem* and G. A. Wiegers, "The Polemical Works of Muḥammad al-Qaysī (*floruit* 1309) and their Circulation in Arabic and Aljamiado among the Muslims in the 14th Century", *al-Qanṭara – Revista de estudios árabes* (Madrid) 15 (1994), pp. 163-199.

Kopp, *Lexicon Tironianum*: Ulrich Friedrich Kopp, *Lexicon Tironianum: Nachdruck aus Kopps 'Palæographia critica' von 1817 mit Nachwort und einem Alphabetum Tironianum von Bernhard Bischoff*, Osnabrück: Otto Zeller, 1965.

Krems 1992 Conference Proceedings: Harry Kühnel, ed., *Kommunikation zwischen Orient und Okzident*, (Sitzungsberichte der Philosophisch-Historischen Klasse der Österreichischen Akademie der Wissenschaften, Band 619, Veröffentlichungen des Instituts für Realienkunde des Mittelalters und der Frühen Neuzeit (Krems), Nr. 16), Vienna: Österreichische Akademie der Wissenschaften, 1994.

Kriss & Kriss-Heinrich, *Volksglaube im Islam*: Rudolf Kriss and Hubert Kriss-Heinrich, *Volksglaube im Bereich des Islam*, I: *Wallfahrtswesen und Heiligenverehrung*, and II: *Amulette, Zauberformeln und Beschwörungen*, Wiesbaden: Otto Harrassowitz, 1960-1962.

Kunitzsch, "*Almagest* Manuscript": Paul Kunitzsch, "A Hitherto Unknown Arabic Manuscript of the *Almagest*", *ZGAIW* 14 (2001), pp. 31-37.

- , *Arabische Sternnamen in Europa*: *idem*, *Arabische Sternnamen in Europa*, Wiesbaden: Otto Harrassowitz, 1959.

- , "Astrolabe Stars": *idem*, "al-Ṣūfī and the Astrolabe Stars", *ZGAIW* 6 (1990), pp. 151-166.

- , "Astrolabe Treatise Ascribed to Messahalla": *idem*, "The Treatise on the Composition and Use of the Astrolabe Ascribed to Messahalla", *Archives internationales d'histoire des sciences* 31 (1981), pp. 42-62, repr. in *idem*, *Studies*, X.
- , "Fachausdrücke": *idem*, "Glossar der arabischen Fachausdrücke in der mittelalterlichen europäischen Astrolabliteratur", *Nachrichten der Akademie der Wissenschaften in Göttingen, I. Philologisch-Historische Klasse*, Jahrgang 1982, Nr. 11, pp. 455-571. [The separatum is paginated 1-117.]
- , "Hindu-Arabic Numerals": *idem*, "The Transmission of Hindu-Arabic Numerals Reconsidered", to appear in *Cambridge DI 1998 Conference Proceedings*.
-, "Letters in Geometrical Diagrams": *idem*, "Letters in Geometrical Diagrams: Greek – Arabic – Latin", *ZGAIW* 7 (1991/92), pp. 1-20.
-, "Role of al-Andalus": *idem*, "The Role of Al-Andalus in the Transmission of Ptolemy's *Planisphaerium* and *Almagest*", *ZGAIW* 10 (1995/96), pp. 147-155.
-, *Sternkatalog des Almagest*: *idem*, *Claudius Ptolemäus – Der Sternkatalog des Almagest – Die arabisch-mittelalterliche Tradition*, 3 vols., Wiesbaden: Otto Harrassowitz, 1986-1991.
-, *Sternnomenklatur der Araber*: *idem*, *Untersuchungen zur Sternnomenklatur der Araber*, Wiesbaden: Otto Harrassowitz, 1961.
- , *Studies*: *idem*, *The Arabs and the Stars*, Northampton: Variorum, 1989.
-, "10th-Century Astrolabe": *idem*, "Traces of a Tenth-Century Spanish-Arabic Astrolabe", *ZGAIW* 12 (1998), pp. 113-120.
- , "Three Dubious Stars": *idem*, "Three Dubious Stars in the Oldest European Table of Astrolabe Stars", *ZGAIW* 13 (1999/2000), pp. 57-69.
-, "Two Star Tables from Muslim Spain": *idem*, "Two Star Tables from Muslim Spain", *Journal for the History of Astronomy* 11 (1980), pp. 192-201, repr. in *idem*, *Studies*, IV.
- , *Typen von Sternverzeichnissen*: *idem*, *Typen von Sternverzeichnissen in astronomischen Handschriften des zehnten bis vierzehnten Jahrhunderts*, Wiesbaden: Otto Harrassowitz, 1966.

Kunitzsch Festschrift: *Sic itur ad astra. Studien zur Geschichte der Mathematik und Naturwissenschaften. Festschrift für den Arabisten*

Paul Kunitzsch zum 70. Geburtstag, Menso Folkerts and Richard P. Lorch, eds., Wiesbaden: Otto Harrassowitz, 2000.

Kunitzsch & Dekker, "Stars on the Carolingian Astrolabe": *idem* and Elly Dekker, "The Stars on the Rete of the So-Called "Carolingian Astrolabe"," in *Vernet Festschrift*, II, pp. 655-672, repr. in Stevens *et al.*, *The Oldest Latin Astrolabe*, new edn.

Kunitzsch & Smart, *Star-Names*: *idem* and Timothy Smart, *Short Guide to Modern Star Names and Their Derivation*, Wiesbaden: Otto Harrassowitz, 1986.

Kunitzsch: See also Folkerts & Kunitzsch.

Kuwait 1990 Hermitage Exhibition Catalogue: *Masterpieces of Islamic Art in the Hermitage Museum*, Kuwait: Dar al-Athar al-Islamiyyah, 1990. [Catalogue of an exhibition held in Kuwait in 1990.]

Labarta & Barceló, *Números y cifras*: Ana Labarta and Carmen Barceló, *Números y cifras en los documentos arábigohispanos*, Cordova: Universidad de Córdoba, Area de Estudios Árabes e Islámicos, Cátedra de Lengua y Literatura Árabes, 1988.

Lacarenza, "Il ragno ebraico dell'astrolabio di Ibn al-Sahlī": Giancarlo Lacerenza, "Nota sul ragno ebraico dell'astrolabio di Muḥammad ibn al-Sahlī", in M. Bernardini, U. Marazzi, A. Saraçgil (eds.), *Turcica et islamica. Studi in memoria di Aldo Gallotta*, Naples: Università degli Studi di Napoli "L'Orientale", 2003, in press.

Lambert, *L'art gothique en Espagne*: Elie Lambert, *L'art gothique en Espagne au XII. et XIII. siècles*, Paris: Laurens, 1931.

Lamrabet, *Mathématiques maghrébines*: Driss Lamrabet, *Introduction à l'histoire des mathématiques maghrébines*, Rabat: privately published by the author, 1994.

Lanci, *Simboliche arabiche*: Michelangelo Lanci, *Trattato delle simboliche rappresentanze arabiche e della varia generazione de musulmani caratteri sopra differenti materie operati*, 3 vols., Paris: Dondey-Dupre, 1845.

Langermann, "Science and the *Kuzarī*": Y. Yzvi Langermann, "Science and the *Kuzarī*", *Science in Culture* 10:3 (1997), pp. 495-522.

- , *Studies*: *idem*, *The Jews and the Sciences in the Middle Ages*, Aldershot: Variorum, 1999.

Laurent, *De abbreviationibus*: Marie-Hyacinthe Laurent, *De abbreviationibus et signis scripturæ gothicæ*, Rome: Institutum Angelicum, 1939.

Lemay, "Arabic Numerals": Richard Lemay, article "Arabic Numerals" in *DMA*.

Lévy, "Fractions en hébreu": Toni Lévy, "Note sur le traitement des fractions dans les premiers écrits mathématiques rédigés en hébreu (XIe et XIIe siècles)", in Benoit *et al.*, eds., *Histoire des fractions*, pp. 277-289.

Lings, *Quranic Calligraphy and Illumination*: Martin Lings, *The Quranic Art of Calligraphy and Illumination*, London: World of Islam Festival Trust, 1976.

London BM Catalogue: F. A. B. Ward, *A Catalogue of European Scientific Instruments in the Department of Medieval and Later Antiquities of the British Museum,* London: British Museum Publications, Ltd., 1981.

López de Toro, *Abreviaturas hispanicas*: José López de Toro, *Abreviaturas hispanicas*, Madrid: Dirección General de Archivos y Bibliotecas, Junta Técnica de Archivos, Bibliotecas y Museos, 1957.

Lorch, "Rudulf of Bruges on the Astrolabe": Richard P. Lorch, "The Treatise of Rudolf of Bruges on the Astrolabe", in *North Festschrift*, pp. 55-100.

Mackay, "Jews in Spain": Angus Mackay, "The Jews in Spain and Portugal", in Kedourie, ed., *Spain and the Jews*, pp. 33-50.

Maddison, "Barber's Astrolabe": Francis R. Maddison, "The Barber's Astrolabe", *Interdisciplinary Scientific Reviews* (London) 17:4 (1992), pp. 349-355.

Madrid BN MSS Catalogue: Martín de la Torre and Pedro Longás, *Catálogo de códices latinos*, Tomo I: *Bíblicos*, Madrid: Biblioteca Nacional, 1935.

Madrid MAN Catalogue: María Angela Franco Mata, *Museo Arqueológico Nacional – Catálogo de la escritura gotica*, 2nd edn., Madrid: Museo Arqueológico Nacional, 1993.

Madrid RAH MSS Catalogue: Elisa Ruiz García, *Real Academia de la Historia – Catálogo de la Sección de códices*, Madrid: Real Academia de la Historia, 1993.

Madrid 1992 Exhibition Catalogue: Juan Vernet and Julio Samsó, eds., *El legado científico andalusí*, Madrid: Ministerio de Cultura, 1992. [Catalogue of an exhibition at the Museo Arqueológico Nacional, Madrid, April-June 1992.]

Madrid 1997 Exhibition Catalogue: Jacques van Damme, Koenraad van Cleempoel, Gerard L'E. Turner, *et al.*, *Instrumentos cientificos del siglo XVI – La corte española y la escuela de Lovaina*, Madrid: Fundación Carlos de Amberes, 1997, with an English text without illustrations published separately as *Scientific Instruments in the Sixteenth Century: The Spanish Court and the Louvain School.* [Catalogue of an exhibition held at the Foundation during 26.11.1997-1.2.1998.]

* *Madrid & Toledo 1987 Colloquium Proceedings*: *VII Coloquio del Comité Internacional de Paleografía Latina. Actas. Madrid-Toledo 29 setiembre - 1 octubre 1987*, Madrid: 1990.

Maier, "Romanische Monatsnamen", A-B: Kurt Maier, "Bemerkungen zu romanischen Monatsnamen auf mittelalterlichen Astrolabien", in *Frankfurt IGN Festband*, pp. 237-254 (A); and *idem*, "Zeugen des Mehrsprachigkeit: mittelalterliche romanische Monatsnamen auf islamischen astronomischen Instrumenten", in Jens Lüdtke, ed., *Romania arabica. Festschrift für Reinhold Kontzi zum 70. Geburtstag*, Tübingen: Gunther Narr, 1996, pp. 251-270 (B).

- , "Astrolab aus Córdoba": *idem*, "Ein arabisches Astrolab aus Córdoba (11. Jh.) mit späteren altkatalanischen Inschriften", in *Saltzer Festschrift*, pp. 119-133.

Maier: see also King & Maier.

Mantello & Rigg, eds., *Medieval Latin*: F. A. C. Mantello and A. G. Rigg, eds., *Medieval Latin: An Introduction and Bibliographical Guide*, Washington, D.C.: The Catholic University of America Press, 1996.

Marín Martínez & Ruiz Asencio, *Paleografía y diplomatica*: Tomás Marín Martínez and José Manuel Ruiz Asencio, *Paleografía y diplomatica*, 2 vols., 2nd edn., Madrid: Universidad Nacional de Educación a Distancia, 1987.

Mateu Ibars, *Braquigrafía de Sumas*: Josefina Mateu Ibars, *Braquigrafía de Sumas – Estudio analítico en la traditio de algunos textos*

manuscritos, incunables e impresos arcaicos (S. XIII-XVI), Barcelona: Publicacions i edicions de la Universitat de Barcelona, 1984.

Mateu Ibars & Mateu Ibars, *Bibliografía paleográfica*: *eadem* and María Dolores Mateu Ibars, *Bibliografía paleográfica,* Barcelona: Universitat de Barcelona, 1974.

- , *Colectanea paleográfica*: *eaedem*, *Colectanea paleográfica de la Corona de Aragón siglos IX-XVIII*, 2 vols., Barcelona: Universitat de Barcelona, 1980.

Mateu y Llopis, *Ponderales monetarios*: Felipe Mateu y Llopis, *Catálogo de los ponderales monetarios del Museo Arqueológico Nacional*, Madrid: Cuerpo facultativo de archiveros, bibliotecarios y arqueólogos, 1934.

Mayer, *Islamic Astrolabists*: Leo A. Mayer, *Islamic Astrolabists and their Works*, Geneva: Albert Kundig, 1956, and a supplement "Islamic Astrolabists: Some New Material", in Richard Ettinghausen, ed., *Aus der Welt der islamischen Kunst*, Berlin: Gebrüder Mann, 1959, pp. 293-296.

- , *Islamic Metalworkers*: *idem*, *Islamic Metalworkers and their Works*, Geneva: Albert Kundig, 1959.

W. Mayer, "Buchstaben-Verbindungen": Wilhelm Mayer, "Die Buchstaben-Verbindungen der sogenannten gotischen Schrift", *Abhandlungen der Königlichen Gesellschaft der Wissenschaft zu Göttingen, Philologisch-Historische Klasse*, N.F., Band 1, Nr. 6, Berlin: Weidmannsche Buchhandlung, 1897.

Melikian-Chirvani, *Iranian Metalwork*: Assadullah Souren Melikian-Chirvani, *Victoria and Albert Museum, Catalogue – Islamic Metalwork from the Iranian World, 8-18th centuries*, London: Her Majesty's Stationery Office, 1982.

Mendoza Eguaras, "Astrolabio de Granada", Angela Mendoza Eguaras, "El astrolabio del Museo Arqueológico de Granada", *Boletín de la Real Academia de Bellas Artes de Granada* 1 (1990), pp. 139-167.

Merlo, *Nomi romanzi dei mesi*: Clemente Merlo, *I nomi romanzi delle stagioni e dei mesi studiati particolarmente nei dialetti ladini, italiani, franco-provenzali e provenzali*, Turin: Ermanno Loescher, 1904.

Michel, *Traité de l'astrolabe*: Henri Michel, *Traité de l'astrolabe*, Paris: Gauthier-Villars, 1947, repr. with a new preface by Francis R. Maddison, Paris: Librarie Alain Brieux, 1989.

Millares Carlo, *Paleografía española*: Agustín Millares Carlo, *Tratado de paleografía española*, 3 vols., Madrid: Espasas-Calpe, 1983.

Millàs Vallicrosa, *Assaig*: José M. Millàs Vallicrosa, *Assaig d'història de les idees físiques i matemàtiques a la Catalunya medieval*, vol. I, (Estudis Universitaris Catalans, sèrie monogràfica I), Barcelona: 1931.

- , "Astrologia de Enrique de Villena", *idem*, "El «Libro de Astrología» de don Enrique de Villena", (first published in 1943), in *idem*, *Estudios*, I, pp. 399-426.

- , *Estudios*, I-II: *idem*, *Estudios* ... and *Nuevos estudios sobre historia de la ciencia española*, (first published Barcelona, 1949 and 1960, respectively), repr. together in 2 vols., Madrid: Consejo Superior de Investigaciones Científicas, 1987.

- , *Traducciones orientales*: *idem*, *Las traducciones orientales en la Biblioteca Capitualar de Toledo*, Barcelona, 1943.

Moreno *et al.*, "Spanish Astrolabe": Roberto Moreno with David A. King and Koenraad van Cleempoel, "An Astrolabe from Sixteenth-Century Spain", *Annals of Science* 59 (2002), pp. 331-362.

Mundó, "Analyse paléographique de l'astrolabe 'carolingien'", in Stevens et al., eds., *Oldest Latin Astrolabe*, pp. 303-321 and 9 figs.

Munich Astrolabe Catalogue: Burkhard Stautz, *Die Astrolabiensammlungen des Deutschen Museums und des Bayerischen Nationalmuseums*, Munich: Oldenbourg, 1999. [See already the summary "Mit dem Himmel in der Hand – Astrolabien und die Astrolabiensammlung des Deutschen Museums", *Kultur & Technik* (Munich: Deutsches Museum) 2 (1997), pp. 38-43.]

Nallino, "Mappamondo di ash-Sharafī": Carlo Alfonso Nallino, "Un mappamondo arabo disegnato nel 1579 da ʿAlī ibn Aḥmad ash-Sharafī di Sfax", *Bollettino della Reale Società Geografica Italiana*, ser. V, 5 (1916), pp. 721-736, repr. in *idem*, *Scritti*, V, pp. 533-548 (not repr. in *Islamic Geography*).

- , *Scritti*, V: *idem*, *Raccolta di scritti editi e inediti* (ed. Maria Nallino), vol. V: *Astrologia – Astronomia – Geografia*, Rome: Istituto per l'Oriente, 1944.

Nancy 28.06.1998 Pamphlet: Anthony J. Turner, with assistance from Emilie Savage-Smith, "Astrolabe du Moyen Âge exceptionel", 6 pp., published by the Hotel des Ventes Anticthermal, Nancy, for the auction on 28 June, 1998, with a privately-distributed English version.

Nasr, *Islamic Science*: Seyyed Hossein Nasr, *Islamic Science – An Illustrated Study*, London: World of Islam Festival Publishing Co., Ltd., 1976, repr. Istanbul: Insan Yayınları, 1989. [A Persian translation *'Ilm dar Islām* was published in Tehran, 1366 HS (= 1988).]

New York JM 1992 Exhibition Catalogue: Vivian B. Mann, Thomas F. Glick, Jerrilynn D. Dodds, eds., *Convivencia – Jews, Muslims and Christians in Medieval Spain*, New York, N.Y.: George Braziller, in association with The Jewish Museum, 1992. [Catalogue of an exhibition held at The Jewish Museum in 1992.]

New York MMA 1993-94 Exhibition Catalogue: John P. O'Neill, ed., *The Art of Medieval Spain, a.d. 500-1200*, New York, N.Y.: The Metropolitan Museum of Art, 1993. [Catalogue of an exhibition at the museum during 18.11.1993-13.3.1994.]

New York MMA 1997 Exhibition Catalogue: Stefano Carboni, *Following the Stars – Images of the Zodiac in Islamic Art*, New York, N.Y.: The Metropolitan Museum of Art, 1997. [Catalogue of an exhibition held during 4.2.-31.8.1997.]

North, "Astrolabe": John D. North, "The Astrolabe", *Scientific American* 230 (1974), pp. 96-106, repr. in *idem*, *Studies*, I, no. 14.

- , *Horoscopes and History*: *idem*, *Horoscopes and History*, (Warburg Institute Surveys and Texts, vol. 12), London: The Warburg Institute, 1986.

- , *Studies*, I: *idem*, *Stars, Minds and Fate – Essays in Ancient and Medieval Cosmology*, London & Ronceverte, W.V.: The Hambledon Press, 1989.

North Festschrift: Arjo Vanderjagt and Lodi Nauta, eds., *Between Demonstration and Imagination: Essays in the History of Science and Philosophy Presented to John D. North*, Leiden: E. J. Brill, 1999.

Nuremberg GNM 1992-93 Exhibition Catalogue: Gerhard Bott, ed., *Focus Behaim-Globus*, 2 vols., Nuremberg: Germanisches Nationalmuseum, 1992. [Catalogue of an exhibition held at the Museum during 2.12.1992-28.2.1993.]

Paris BN Catalogue: Arlette Nègre, *Trésors de l'Islam au Cabinet des Médailles*, Paris: Bibliothèque Nationale, Département des Monnaies, Médialles et Antiques, 1981.

Paris BN 1973 Exhibition Catalogue: *Nicolas Copernic ou La révolution astronomique*, Paris: Bibliothèque Nationale, 1973.

* *Paris CNRS 1972 Colloquium Proceedings*: *La paléographie hébraïque médiévale*, Paris: Centre Nationale de la Recherche Scientifique, 1974. [Proceedings of a colloquium held at C.N.R.S. during 11.-13.9.1972.]

Paris IMA Catalogue: Jeanne Mouliérac, "La Collection Marcel Destombes", in A. J. Turner, ed., *Astrolabica No. 5 – Études 1987-1989*, Paris, Institut du Monde Arabe and Société internationale de l'astrolabe, 1989, pp. 77-126.

Paris IMA 1993-94 Exhibition Catalogue: Sophie Cluzan, Eric Delpont and Jeanne Mouliérac, eds., *Syrie – mémoire et civilisation*, Paris: Institut du Monde Arabe, 1993. [Catalogue of an exhibition held during 14.9.1993-28.2.1994.]

Paris GP 1998 Exhibition Catalogue: *L'Art au temps des rois maudits Philippe le Bel et ses fils 1285-1328*, Paris: Éditions de la Réunion des musées nationaux, 1998. [Catalogue of an exhibition held at the Galeries nationales du Grand Palais during 17.3.-29.6.1998.]

Pavón Maldonado, *El arte hispano-musulman*: Basilio Pavón Maldonado, *El arte hispano-musulman en su decoración geometrica,* Madrid: Ministerio de Asunto Exteriores, Instituto Hispano-Árabe de Cultura, 1975.

Peignot & Adamoff, *Chiffres*: Jérôme Peignot and Georges Adamoff, *Le chiffre*, [Paris]: Crédit Lyonnais, 1969.

Piccard, "Les chiffres chez les anciens et les modernes": [Jules] Piccard, "Mémoire sur la forme et la provenance des chiffres servant à la numération décimale chez les anciens et les modernes", *Bulletin des séances de la Société vaudoise des sciences naturelles* (Lausanne) 6 (1858-60), pp. 163-194 and 1 pl.

Poulle, "L'astrolabe": Emmanuel Poulle, "L'astrolabe", *La Recherche* (Paris) 178 (juin, 1986), pp. 756-765.

- , *Fusoris*: *idem*, *Un constructeur d'instruments astronomiques au 15e siècle – Jean Fusoris*, Paris: Honoré Champion, 1963.

- , *Instruments du Moyen Age*: *idem*, *Les instruments astronomiques du Moyen Age*, (first published in *Le Rouban Rouge* (Paris), no. 32 (mars 1967), pp. 18-29), revised edn., *Astrolabica* (Société internationale de l'astrolabe), no. 3, Paris: Alain Brieux, 1983.

- "Peut-on dater les astrolabes?": *idem*, "Peut-on dater les astrolabes médiévaux?", *Revue de l'histoire des sciences et de leurs applications* (Paris) 9 (1956), pp. 301-322.

Poupardin, "Abréviation": René Poupardin, "A propos de l'abréviation ⁹ = S", *Bibliothèque de l'École des Chartes* 68 (1907), pp. 426-427. [See also Delisle & Traube, "Signe abréviatif".]

Price *et al.*, *Checklist*: Derek J. de Solla Price *et al.*, *A Computerized Checklist of Astrolabes*, New Haven, Conn.: Yale University, Department of History of Science and Medicine, 1973.

Prou, *Manuel de paléographie latine et française*: Maurice Prou, *Manuel de paléographie latine et française du VII^e au XVII^e siècle suivi d'un dictionnaire des abréviations avec 23 facsimilies en phototypie* ... , 2nd edn., Paris: Alphonse Picard, 1892.

Rennes 1983 Conference Proceedings: Xavier Barral i Altet, ed., *Artistes, artisans et production artistique au moyen âge*, 3 vols. (I: *Les hommes*; II: *Commande et travail, III: Fabrication et consommation de l'œuvre*), Paris: Picard, 1987-90. [See Sed-Rajna, "Ateliers de manuscrits hébreux".]

Rosenfeld & Matvievskaya, *MAMS*: Galina P. Matvievskaya and Boris A. Rosenfeld, *Matematiki i astronomi musulmanskogo srednevekovya i ikh trudi*, Moscow: Nauk, 3 vols., 1983.

Salamanca MSS Catalogue: Óscar Lilao Franca and Carmen Castrillo González, *Catálogo de manuscritos de la Biblioteca Universitaria de Salamanca*, I: *Manuscritos 1-1679 bis*, Salamanca: Ediciones Universidad de Salamanca, 1997.

Saliba: see Goldstein & Saliba.

Saltzer Festschrift: Peter Eisenhardt, Frank Linhart and Kaisar Petanides, eds., *Der Weg der Wahrheit – Aufsätze zur Einheit der Wissenschaftsgeschichte – Festgabe zum 60. Geburtstag von Walter G. Saltzer*, Hildesheim: Georg Olms, 1999.

Samsó, *Ciencias en al-Andalus*: Julio Samsó, *Las ciencias de los antiguos en al-Andalus*, Madrid: Editorial Mapfre, 1992.

- , "Exact Sciences in Al-Andalus": *idem*, "The Exact Sciences in Al-Andalus", in Jayyusi, ed., *Muslim Spain*, II, pp. 952-973.
- , "Maghribī *Zījes*": *idem*, "An Outline of the History of Maghribī *Zījes* from the End of the Thirteenth Century", *Journal for the History of Astronomy* 29 (1998), pp. 93-102.
- , *Studies*: *idem*, *Islamic Astronomy and Medieval Spain*, Aldershot: Variorum, 1994.

Samsó: see also Cátedra & Samsó and Vernet & Samsó.

Sánchez Pérez, *Biografías*: José Agusto Sánchez Pérez, *Biografías de matemáticos árabes que florecieron en España*, Madrid: Real Academia de Ciencias Físicas y Exactas, 1921, repr. Granada: Sierra Nevada, 1995.

Santa Cruz 1985 Exhibition Catalogue: Juan Vernet and Julio Samsó, eds., *Instrumentos astronómicos en la España medieval – su influencia en Europa*, Santa Cruz de la Palma: Ministerio de Cultura, Dirección General de Bellas Artes y Archivos, 1985. [Catalogue of an exhibition held in Santa Cruz during June and July, 1985.]

Sarton, *IHS*: George Sarton, *An Introduction to the History of Science*, 5 parts in 3 vols., Baltimore, Md.: Wilkins & Wilkins, for the Carnegie Institution of Washington, 1927-1948, repr. Huntington, N.Y.: Robert E. Krieger, 1975.

Savage-Smith: see *Nancy 28.06.1998 Pamphlet*.

Scheindlin, "Jews in Muslim Spain": Raymond P. Scheindlin, "The Jews in Muslim Spain", in Jayyusi, ed., *Muslim Spain*, I, pp. 188-200.

Schiaparelli, "Note paleografiche": Luigi Schiaparelli, " Note paleografiche. Segni tachigrafici nelle notae iuris", *Archivio storico italiano* 73 (1915), pp. 241-275, and "Le Notae iuris e il sistema delle abbreviature medieval", *ibid.*, pp. 275-322, both repr. as one continuous article in *idem*, *Note paleografiche*, ed. G. Cencetti, Turin, 1969, pp. 94-186.

Schimmel, *Islamic Calligraphy*: Annemarie Schimmel, *Calligraphy and Islamic Culture*, New York & London, New York University Press, 1984.

Sed-Rajna, "Ateliers de manuscrits hébreux": Gabrielle Sed-Rajna, "Ateliers de manuscrits hébreux dans l'Occident médiéval", in *Rennes 1983 Conference Proceedings*, I, pp. 339-352.

- , "Toledo or Burgos?": *eadem*, "Toledo or Burgos?", *Journal of Jewish Art* 2 (1975), pp. 6-21.

Sepharad: a special issue of *Jewish Art* 18 (1992).

Shatzmiller, "Professions in Muslim Spain": Maya Shatzmiller, "Profession and Ethnic Origin of Urban Labourers in Muslim Spain: Evidence from a Moroccan Source", *Awrâq – Revista editada por el Instituto Hispano-Árabe de Cultura* (Madrid) 5-6 (1982-83), pp. 149-159.

Sigler, *Fibonacci's Liber Abaci*: Laurence E. Sigler, *Fibonacci's Liber Abaci – A Translation into Modern English of Leonardo Pisano's Book of Calculation*, New York, Berlin & Heidelberg: Springer-Verlag, 2002.

Singer *et al.*, eds., *History of Technology*: Charles Singer *et al.*, eds., *A History of Technology*, 5 vols., Oxford: Clarendon Press, 1954-58.

Singmaster, "Mathematical Gazetteer of Britain": David Singmaster, "Mathematical Gazetteer of Britain: #10 Hackforth to Kirkaldy", *Newsletter of the British Society for the History of Mathematics*, no. 37 (Summer 1998), pp. 15-19.

Smith, *Rara Arithmetica*: David Eugene Smith, *Rara Arithmetica: A Catalogue of the Arithmetics Written before the Year MDCI with a Description of those in the Library of George Arthur Plimpton of New York*, Boston & London: Ginn & Co., 1908, 4th edn., repr. New York, N.Y.: Chelsea Publishing Company, 1970.

Sotheby's 16.10.1997 Catalogue: *Islamic Art, Sotheby's London Thursday 16 October 1997*, London: Sotheby's, 1997.

Sotheby's 18.10.2001 Catalogue: *Sotheby's – Arts of the Islamic World ... London 18 October 2001*, London: Sotheby's, 2001.

Stafford & Ware, *Dictionary of Ornament*: Maureen Stafford and Dora Ware, *An Illustrated Dictionary of Ornament*, London: George Allen & Unwin, 1974.

Stautz, "Astrolab aus 1420": Burkhard Stautz, "Ein Astrolab aus dem Jahr 1420", *NTM: Internationale Zeitschrift für Geschichte und Ethik der Naturwissenschaften, Technik und Medizin* 5 (1997), pp. 142-159.

- , *Untersuchungen*: *idem*, *Untersuchungen von mathematisch-astronomischen Darstellungen auf mittelalterlichen Instrumenten*

islamischer und europäischer Herkunft, Bassum: Verlag für Geschichte der Naturwissenschaften und der Technik, 1997.

Stautz: see also *Munich Astrolabe Catalogue*.

Steinschneider, *Arabische Literatur der Juden*: Moritz Steinschneider, *Die arabische Literatur der Juden*, Frankfurt am Main: J. Kauffmann, 1902, repr. Hildesheim: G. Olms, 1986.

Stevens *et al.*, eds., *Oldest Latin Astrolabe*: Wesley Stevens, Guy Beaujouan, and Anthony J. Turner, eds., *The Oldest Latin Astrolabe*, *Physis* (Rome) 32:2-3 (1995) [published 1996], new edition, with additions, Florence: Olschki, 1998.

Suter, "Rechenbuch von al-Ḥaṣṣār": Heinrich Suter, "Das Rechenbuch von Abū Zakarījā el-Ḥaṣṣār", *Bibliotheca Mathematica*, 3. Folge, 2 (1901), pp. 12-40, repr. in *idem*, *Schriften*, II, pp. 115-143.

Suter, *Schriften*: Fuat Sezgin, ed., *Heinrich Suter, Zur Geschichte der Mathematik und Astronomie im Islam*, 2 vols., Frankfurt am Main: Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 1986.

Terrasse, *L'art hispano-mauresque*: Henri Terrasse, *L'art hispano-mauresque des origines au XIII^e^ siècle*, (*Publications de l'Institut des hautes études marocaines*, XXV), Paris: G. van Oest, 1932.

- , *L'Espagne du moyen âge*: *idem*, *L'Espagne du moyen âge – civilisation et arts*, Paris: Fayard, 1966.

Teruel 1988 Exhibition Catalogue: *Exposición de arte, tecnología y literatura hispano-musulmanes*, Madrid: Ferreira, 1988. [Catalogue of an exhibition at the Museo Provincial de Teruel during September-October, 1988.]

Thomson, *Latin Bookhands*: S. Harrison Thomson, *Latin Bookhands of the Late Middle Ages*, Cambridge: Cambridge University Press, 1969.

Toledo MSS Catalogue: Klaus Reinhardt and Ramón González, *Catálogo de códices bíblicos de la Catedral de Toledo*, Madrid: Fundación Ramón Areces, 1990.

Tomba, "Astrolabi", A-D: Tullio Tomba, "Due astrolabi latini del XIV secolo conservati a Milano", *Physis* 8 (1966), pp. 295-306; *idem*, "Nuove osservazioni sui due astrolabi latini del XIV secolo conservati a Milano", *Physis* 10 (1968), pp. 119-122; *idem*, "Un astrolabio del XIV secolo di probabile origine italiana", *Physis* 12 (1970), pp. 82-87;

and *idem*, "Tre astrolabi latini, del XIV secolo, conservati in Italia", *Rassegna di Studi e di Notizie* (Milan), 20 (Anno XXII [= 1996]) (the offprint is unpaginated).

Treue, *Kulturgeschichte der Schraube*: Wilhelm Treue, *Kulturgeschichte der Schraube von der Antike bis zum 18. Jahrhundert*, Munich: F. Bruckmann, 1955.

Tropfke, *Geschichte der Elementarmathematik*: Johannes Tropfke, *Geschichte der Elementarmathematik*, 4. Auflage, Band 1: *Arithmetik und Algebra*, revised by Kurt Vogel, Karin Reich, Helmuth Gericke, Berlin & New York: Walter de Gruyter, 1980.

A. Turner: see *Amsterdam 1990 Exhibition Catalogue*; *Nancy 28.06.1998 Pamphlet*; and Stevens *et al.*, *Oldest Latin Astrolabe*.

G. Turner, "Carolingian Astrolabe": Gerard L'E. Turner, "The Craftsmanship of the 'Carolingian' Astrolabe, IC 3042", in Stevens *et al.*, eds., *Oldest Latin Astrolabe*, pp. 421-432, repr. in Turner, *Studies*.

- , "Dating Astrolabes": *idem*, "A Critique of the Use of the First Point of Aries in Dating Astrolabes", in *Kunitzsch Festschrift*, pp. 548-554, repr. in *idem*, *Studies*.

- , *Elizabethan Instruments*: *idem*, *Elizabethan Instrument Makers – The Origins of the London Trade in Precision Instrument Making*, Oxford: Oxford University Press, 2000.

- , "Giusti's Workshop": *idem*, "The Florentine Workshop of Giovan Battista Giusti, 1556 - *c.* 1575), *Nuncius – Annali di storia della scienza* (Florence) 10 (1995), pp. 131-172, repr. in *idem*, *Studies*.

- , *Studies*: *idem*, *Renaissance Astrolabes and Their Makers*, Aldershot: Variorum-Ashgate, 2003.

G. Turner & Dekker, "Astrolabe by Mercator": *idem* and Elly Dekker, "An Astrolabe Attributed to Gerard Mercator, *c.* 1570", *Annals of Science* 50 (1993), pp. 403-443, repr. in Turner, *Studies*.

- - , "Three Astrolabes by Mercator": *eidem*, "The First Three Instruments of Gerard Mercator to be Identified: Three Astrolabes", in Ruth Löffler, Gernot Tromnau *et al.*, eds., *Gerhard Mercator und die Welt*, Duisburg: Kultur- und Stadthistorisches Museum, 1994, pp. 197-210, repr. in Turner, *Studies*.

G. Turner: see also King & G. Turner.

G. Turner Festschrift: Robert G. W. Anderson, James A. Bennett and William F. Ryan, eds., *Making Instruments Count – Essays on Historical Scientific Instruments Presented to Gerard L'Estrange Turner*, Aldershot: Variorum, 1993.

Ullman, "Abecedaria": Berthold Louis Ullman, "Abecedaria and their Purpose", *Transactions of the Cambridge Bibliographical Society* 3 (1961), pp. 181-186 and pl. II.

Usón Sese, *Escritura en Aragón*: Mariano Usón Sese, *Contribución al estudio de la cultura medieval aragonesa – la escritura en Aragón del siglo XI al XVI*, Saragossa: Universidad de Zaragoza, 1940.

van Cleempoel, *Louvain Instruments*: Koenraad van Cleempoel, *A* Catalogue Raisonné *of Scientific Instruments from the Louvain School, 1530 to 1600*, (*De diversis artibus*: Collections of Studies from the International Academy of the History of Science, vol. 65 (N.S. 28)), Turnhout (B): Brepols, 2002.

Venice 1993-94 Exhibition Catalogue: Giovanni Curatola, ed., *Eredità dell'Islam – Arte islamica in Italia*, Milan: Silvana, 1993. [Catalogue of an exhibition held at the Palazzo Ducale in Venice during 30.10.1993-30.4.1994.]

Vera, *MME*: Francisco Vera, *La matemática de los musulmanes españoles*, Buenos Aires: Editorial Nova, 1947.

Vernet, "La conjunción del barbero": Juan Vernet, "La conjunción del barbero de Baghdad", (first published in 1966), repr. in *idem*, *Estudios*, I, pp. 301-303.

- , *Estudios*, I-II: *idem*, *Estudios sobre historia de la ciencia medieval*, Barcelona: Universidad de Barcelona & Bellaterra: Universidad Autónoma de Barcelona, 1979, and *De 'Abd al-Raḥmān I a Isabel II – Recopilación de estudios dispersos ...* , Barcelona: Instituto "Millás Vallicrosa" de Historia de la Ciencia Árabe, 1989.

Vernet, ed., *Estudios*, I-II: *idem*, ed., *Textos y estudios sobre astronomía española en el siglo XIII*, and *Nuevos estudios sobre astronomía española en el siglo de Alfonso X*, Barcelona: Universidad de Barcelona, 1981 and 1983.

- & Samsó, "Science in Andalusia": *idem* and Julio Samsó, "The Development of Arabic Science in Andalusia", in *EHAS*, I, pp. 243-275.

Vernet Festschrift: Josep Casulleras and Julio Samsó, eds., *From Baghdad to Barcelona. Studies in the Islamic Exact Sciences in Honour of Professor Juan Vernet*, 2 vols., Barcelona: Instituto "Millás Vallicrosa" de Historia de la Ciencia Árabe, 1996.

Vielliard, "Horlogers catalans": Jeanne Vielliard, "Horloges et horlogers catalans à la fin du Moyen Âge", *Bulletin Hispanique* 63 (1961), pp. 161-168.

Ward, *Islamic Metalwork*: Rachel Ward, *Islamic Metalwork*, London: British Museum Press, 1993.

Washington FGA 1986 Exhibition Catalogue: Esin Atıl, W. T. Chase and Paul Jett, *Islamic Metalwork in the Freer Gallery of Art*, Washingon, D.C.: Smithsonian Institution, Freer Gallery of Art, 1985. [Catalogue of an exhibition during 27.9.1985-5.1.1986.]

Washington NMAH Catalogue: Sharon Gibbs with George Saliba, *Planispheric Astrolabes from the National Museum of American History*, Washington, D.C.: Smithsonian Institution Press, 1984.

Welch, *Muslim Calligraphy*: Anthony Welch, *Calligraphy in the Arts of the Muslim World*, Austin, Texas: University of Texas Press, in cooperation with The Asia Society, New York, 1979. [Catalogue of an exhibition at the Asia House Gallery, New York, in 1979.]

* Winkler, *Muhammedanische Zauberei*: H. A. Winkler, *Siegel und Charaktere in der muhammedanischen Zauberei*, (*Studien zur Geschichte und Kultur des islamischen Orients, Zwanglose Beihefte zu der Zeitschrift* Der Islam, Heft 7), Berlin & Leipzig: C. H. Becker, 1930.

Wischnitzer, *Jewish Crafts*: Mark Wischnitzer, *A History of Jewish Crafts and Guilds*, New York, N.Y.: David, 1965.

Woepcke, "Arabisches Astrolabium": Franz Woepcke, "Über ein in der königlichen Bibliothek zu Berlin befindliches arabisches Astrolabium", *Abhandlungen der Königlichen Akademie der Wissenschaften zu Berlin* (1855), pp. 1-31 (separatum), repr. in Fuat Sezgin, ed., *Franz Woepcke – Études sur les mathématiques arabo-islamiques*, 2 vols., Frankfurt am Main: Institut für Geschichte der Arabisch-Islamischen Wissenschaften, II, 1986, pp. 131-165.

Wolpe, "Florilegium Alphabeticum": Berthold L. Wolpe, "Florilegium Alphabeticum: Alphabets in Medieval Manuscripts", in A. S. Osley,

ed., *Calligraphy and Palaeography: Essays Presented to Alfred Fairbank on his 70th Birthday*, London: Faber and Faber, 1965, pp. 69-74 and pls. 24-29.

Würth & Konstanz 1995 Exhibition Catalogue: *Die Schraube zwischen Macht und Pracht – Das Gewinde in der Antike*, Sigmaringen: Jan Thorbecke, 1995. [Catalogue of an exhibition held at the Museum Würth in Künzelsau-Gaisbach during 8.4.-16.7.1995 and at the Archäologisches Landesmuseum Baden-Württemberg, Außenstelle Konstanz, during 30.7.-29.10.1995.]

Yarza, *Arte hispánico medieval*: Joaquín Yarza, *La edad media*, vol. II of *Historia del arte hispánico*, Madrid: Alhambra, 1980.

de Zambaur, *Manuel*: E. de Zambaur, *Manuel de généalogie et de chronologie pour l'histoire de l'Islam*, first published Hannover, 1927, repr. Bad Pyrmont: Heinz Lafaire, 1955.

ZGAIW: *Zeitschrift für Geschichte der arabisch-islamischen Wissenschaften* (Frankfurt am Main).

Ziegler, *Black Death*: Philip Ziegler, *The Black Death*, (first publ. London: Collins, 1969), London: Penguin Books, 1982 edn.

Zinner, *Astronomische Instrumente*: Ernst Zinner, *Deutsche und niederländische astronomische Instrumente des 11.-18. Jahrhunderts*, 2nd rev. edn., Munich: C. H. Beck, 1972.